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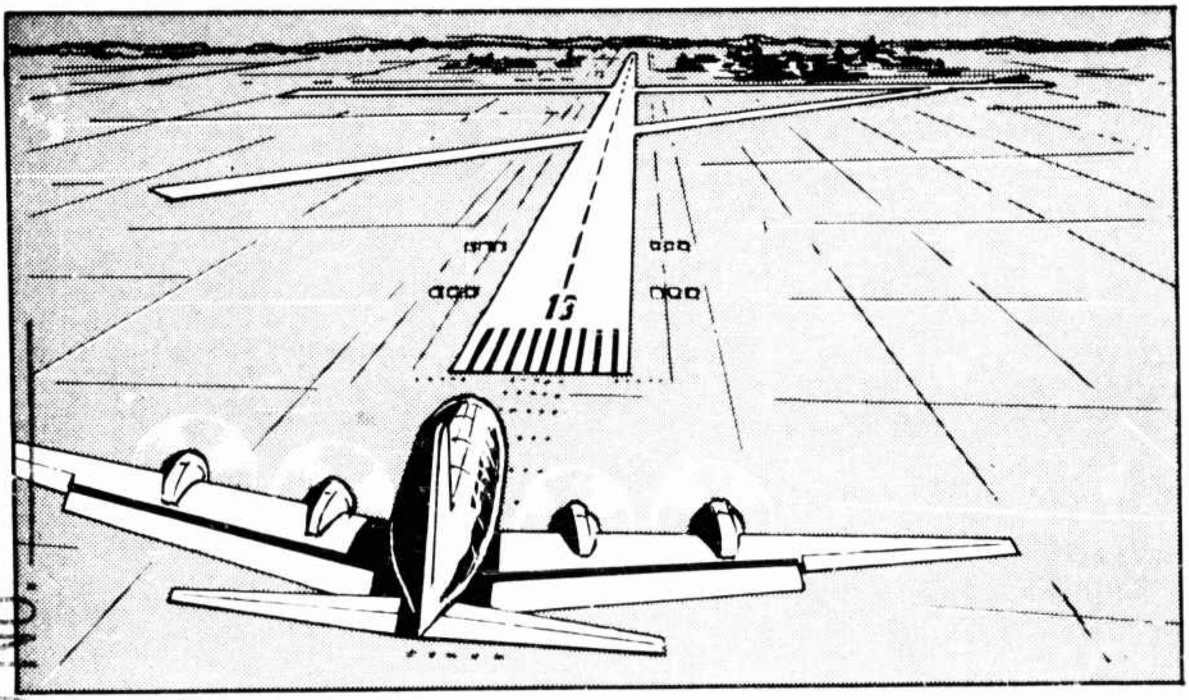

A REPORT ON

INSTALLATION AND TESTING OF VISUAL GLIDE PATH INDICATORS

JUNE 1960

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Prepared by

NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
ATLANTIC CITY, NEW JERSEY

FINAL REPORT

INSTALLATION AND TESTING OF VISUAL GLIDE PATH INDICATORS

TASK ASSIGNMENT NO. D-2-8045

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This report is based on a technical evaluation of equipment and procedures available to the Bureau of Research and Development. It has been reviewed by the Agency and is approved for distribution.

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ABSTRACT

Flight tests were conducted to comparatively evaluate five different types of visual glide path indicators. The systems installed at the National Aviation Facilities Experimental Center (NAFEC) were: Westinghouse Tri-Color, Navy Mirror, USAF Interim Mirror, Australian Cumming-Lane, and British RAE. All of the systems were set up on Runway 13, and as nearly as possible, each system was adjusted to the same vertical angle as the ILS glide path.

A wide cross section of pilots from all segments of aviation participated. A cross section of aircraft was employed, from a Piper Tri-Pacer to the Boeing 707.

Initial testing was directed toward selecting the more promising systems followed by concentrated testing and comparative evaluation of the selected systems. Accordingly, the last six weeks of the program were devoted to comparative evaluation of the Australian Cumming-Lane and the British RAE system.

Subjective data indicate that more pilots prefer the RAE system than prefer the Cumming-Lane. All pilots but one indicated that a requirement exists, under certain conditions, for visual glide path assistance.

Theodolite recordings show that no significant differences exist in the maximum range at which the lights can be seen (with respect to the systems named above), or in the maximum range at which guidance is available. The RAE system, however, provides guidance to a lower altitude than does the Cumming-Lane system.

It is recommended that the RAE Visual Glide Path Indicator be adopted as the United States standard.

PURPOSE

The purpose of this task was to install and evaluate, under actual service conditions, visual glide path indicators and to recommend a system for adoption as the United States standard.

SUMMARY

Visual Glide Path Indicators were installed to provide approaches to Runway 13, as nearly as possible coincident with the vertical angle of the ILS glide slope. Prior to starting the task flights, a complete ILS flight check was conducted by FAA flight inspection personnel.

The flight program was divided into two parts, each of approximately 6 weeks duration. The first part was devoted to evaluating all five systems with a view to selecting the most promising for further detailed testing. The last six weeks were directed toward selection of a system to be recommended as the national standard.

Systems were evaluated by using pilot reaction questionnaires and optical and electronic tracking instrumentation. Recorded data were reduced by the NAFEC electronic computer facilities.

Operational performance data were analyzed and considered along with other factors in order to make a final selection of a Visual Glide Path Indicator System to be recommended as the national standard.

INTRODUCTION

Development and testing of visual glide path indicators are not new in the field of airport lighting and visual aids. The United States Air Force, United States Navy, Royal Aircraft Establishment, Australian Department of Supply, Civil Aeronautics Administration (now Federal Aviation Agency), and other agencies have experimented with, and tested, various ideas and devices. Landing accident statistics have shown a marked increase in recent years as the number of jet aircraft in operation have increased. There has been an attendant increase in interest in visual glide path indicators on the part of all aircraft operators. Internationally, the problem of visual guidance has been recognized by ICAO, and that group has recommended an accelerated program to select a system to be adopted as the standard.

The test program at the National Aviation Facilities Experimental Center (NAFEC) used a somewhat different approach than that used in previous tests. While earlier tests used a very small number of highly experienced airline and/or military pilots, the NAFEC program called for participation in the tests by a large number of pilots comprising a wide cross section of the aviation industry. The same concept was applied to aircraft with at least 26 types of aircraft participating.

In certain of the earlier tests, the results were criticized because equipment was not constructed properly. To avoid this pitfall, it was decided to use a production system where possible, and strict adherence to specifications provided on the systems. Accordingly, a complete RAE system was purchased from the British manfacturer and installed in accordance with his specifications. The Mirror system tested was a standard portable system furnished by the U. S. Navy. The Westinghouse Tri-Color projectors were production items. The Cumming-Lane system was built to duplicate the Australian components as nearly as possible. One exception here is that the red flashing undershoot light was omitted. This decision was based upon the fact that the actual guidance being tested was to be derived from the bars, and also upon the fact that Australian experience indicated that pilots were rarely conscious of the red lights. Finally, the USAF Interim Mirror system, dubbed "Meatball," was copied from a similar installation at Richards-Gebaur Air Force Base, Missouri. The NAFEC installation of the latter used higher intensity lamps.

DISCUSSION

General

Five systems of visual glide path indicators to be comparatively evaluated posed a problem due to the large number of approaches required. In view of the fact that the task assignment called for a wide cross section of pilots and aircraft, it appeared advisable to limit the first scope of the task. Therefore, the first portion of the flight test program, from February 16 to March 31, was devoted to making a determination of the system showing the greatest promise. Since the program had been delayed due to late arrival of some of the equipment, it was decided to use the more expensive-to-operate aircraft (KC-135, Boeing 707) during the latter part of the program. The early test results showed that of the five systems, the Australian Cumming-Lane and the British RAE (also called Calvert) systems would best meet the requirements of all users.

Installation

All systems tested were installed on the approach end of Runway 13. This was so that, for test purposes, the ILS glide slope could be used, if necessary, as a cross reference. Participating pilots were asked not to use the ILS; however, except during familiarization runs, and to turn it off when making recorded runs. All of the devices were installed so that they were independent of the normal runway lighting circuit. Controls were housed in a small building approximately 1,000 feet to the side of the touchdown area. An exception to this was the Navy Mirror, which was operated by power from a portable generator. The selector panel was wired so that only one system could be selected at a time. Further information on electrical circuitry is included in Appendix I.

Description of Systems

a. The Navy Mirror system consists of a concave mirror 4 feet high and 3 feet wide, flanked by horizontal bars of green lights, extending approximately 8 feet out from the mirror, midway up the sides of the mirror. A row of amber lamps, about 4 feet long, is positioned on the ground 150 feet toward the threshold from the mirror, and aimed at the center of the mirror. The concave surface of the mirror reflects the light from the source lamps back toward the pilot as an amber ball of light. When the pilot is high on the glide slope, the amber ball appears above the line of green lamps, and if he is low, the amber light appears

below the green lights. The objective of the pilot is to keep the reflection of the amber lights aligned horizontally with the green bars. The glide path angle can be changed by tilting the mirror foward or back to decrease or increase the angle, respectively. In order to add versatility to the equipment, the NAFEC electrical shop modified the intensity control so that separate Variacs were available to adjust the intensity of the amber and green lights independently. The mirror was positioned on the left side of the runway 1,000 feet from threshold. The equipment is shown in Fig. 2.

b. The Interim Mirror (USAF Meatball) represents an attempt to provide the same presentation as the Navy Mirror, but without using a mirror. This installation consists of two bars of green lamps, each bar 7 feet long, mounted on frangible stanchions. The bars are mounted in line, with a gap between the two stanchions of 14 feet. The green lamps are 5 feet 11 inches above the runway. Mounted behind the green lamps (as viewed from the threshold) is a cluster of four amber lamps, mounted on a frangible stanchion so that the center of the cluster is 3 feet 10 inches above the runway. The amber cluster is 60 feet farther from threshold than the green bars, and is located slightly outboard from the center of the gap between the green lights. This is to allow the amber lamps to be viewed from a position approximately over the threshold without moving behind the inboard row of green lights. The presentation of this system is exactly as in the mirror system, the amber lights are aligned with the green to stay on the glide path. If the amber ball moves above the green bars, the aircraft is high, and vice versa for a low position. The array of lights is set up on the left side of the runway, so that the glide path intersects the runway approximately 1,050 feet from the threshold. This system is shown in Fig. 3.

c. An entirely different principle is used in the Westinghouse Tri-Color indicator (see Fig. 4). A complete system consists of two projectors, one mounted on each side of the runway opposite the 1,000-foot point. Each projector emits a single beam, split into yellow, green, and red sectors by a filter. The unit is aimed up the glide path at the proper angle so the pilot sees yellow light if high, green light when on the glide path, and red light if low. The horizontal beam spread is 15°. The vertical spread of the yellow sector is 7°, the green is 2°, and the red is 6°, for a total of 15°. In order to distinguish the light from other steady-burning lights, the beam is interrupted about 40 times per minute by a shutter actuated by a small electric motor. The lines separating the colors are very sharp. This has caused the manufacturer to recommend that the unit on the left side of the runway be aimed $1/2^{\circ}$ higher than the

one on the right, which is set to the desired glide angle. This will warn the pilot of an impending descent below the glide path, since he will intercept the red beam of the left-hand unit before leaving the green beam of the right-hand unit. Conversely, a deviation toward the high side will cause the yellow beam of the right-hand unit to become visible first.

d. The Cumming-Lane device, also known as Precision Visual Glide Path and Double-Bar Ground Aid, makes use of the ability of the human eye to detect misalignments in bars of light. It consists of three elevated amber lamps on frangible wooden poles, located 170 feet from each side of the runway, opposite a point 500 feet from the threshold. On each side of the runway at a point 1, 000 feet from the threshold, a row of five white lights is installed at the level of the runway centerline. Embedded in the centerline of the runway 1, 000 feet from the threshold is a low-intensity white aiming light (see Figs. 5 through 8). The desired glide path determines the height of the elevated amber lamps above the white lights. The NAFEC installation (approximately 2. 6°) required the amber lights to be 23 feet 6 inches above the white lights. If the pilot is on the glide path, the center of the array, or the row of white lights, will be aligned with the amber, so that he sees three amber lights, five white lights, the aiming light, five more white lights, and three more amber lights in a row, all perfectly aligned. If the aircraft goes above the glide path, the white lights will move above the amber, and if the aircraft goes low, the white lights will move below the amber. A complete system also incorporates a high-intensity red flashing light which should become visible to the pilot when his wheels infringe upon a predetermined obstruction clearance plane. This feature was deleted from the NAFEC test installation because the guidance being evaluated is obtained solely from the bars. The undershoot lights are added safety features which are desirable but which have no bearing upon the guidance principle.

e. The system developed at the Royal Aircraft Establishment, and known as the RAE Angle of Approach Indicator (AAI), uses still another principle. The complete system consists of 12 light source units arranged in bars, with three units placed on each side of the runway, opposite the 750-foot mark (from threshold) and three on each side of the runway at the 1, 250 foot mark. Each unit is about 4 feet 6 inches square, and contains three high-intensity sealed-beamed lamps and three filters, the upper half of which is red and the lower half clear, mounted immediately in front of the lamps. A horizontal slit across the front of the box, about 2 inches wide, is at the focus of the lamp. The effect, then, is somewhat like a pinhole camera, so that an observer viewing the slit from a high angle sees white light. As his viewpoint is

lowered, the light changes in color through pink to red. By adjusting the tilt of the box so that the bottom of the white beam is at the desired glide slope angle, the arrangement of all the units then will define a safe glide-path corridor. When on the proper glide path, the pilot is in effect over-shooting the bars nearer the threshold, and undershooting the bars farther down. Thus, he will see the nearer bars as white and the farther bars as red. A position below the glide path will cause both rows of light to be red, and a high position will cause both bars to be white. Impending departure from the glide path is indicated to the pilot by a transition in color from red through pink to white or vice versa. A movement to the high side will cause the farther bars to change from red through pink to white. A descent below the glide path will change the nearer bars from white through pink to red. The RAE system is shown in Figs. 9 through 12.

Data Collection

Because the test directive required a wide cross section of pilots and aircraft, the first step in the design of the program was to request assistance from many sources. Accordingly, letters were sent to the military services and to other aviation organizations, soliciting pilot volunteers. The response provided more than a hundred subjects before completion of the flight phase of the program. Subjective data were obtained by means of a questionnaire, Appendix II, in which pilots expressed opinions on the various systems with respect to a number of aspects. (After the task was limited to two systems, the questionnaire was not redesigned, but pilots were briefed to apply the questions and responses to the two remaining devices and to ignore the three which had been eliminated.) Objective data were obtained by optical tracking with Contraves phototheodolite equipment. Film was exposed at a rate of 5 frames per second, with a reading of the film every 15th frame. This gave a position each 3 seconds. The theodolite runs were designed so that a mark was made on the film when the pilot saw the lights of the system in use, when he had guidance (high, low, or on-course), and when guidance was lost as the touchdown point was approached.

A briefing brochure was prepared which outlined the nature of the test program, gave brief descriptions of what the pilot could expect to see, and presented color plates of an artist's conception of the pilot's view of each system. Test procedure information, such as frequencies, call signs, traffic patterns, required reports and so forth also was included. The brochure was distributed in advance to prospective participants so that the briefing time required on their arrival could be held to a minimum. A questionnaire was included in the brochure so that

pilots would know what particular aspects were to be looked for. Just prior to flight, the subject pilots were given a verbal briefing, which expanded upon the material contained in the brochure, and during which questions were answered. When possible, the pilots were transported to the runway to inspect the various items of equipment in each system.

Experience of participating pilots ranged from a private pilot with 500 hours to an ex-airline captain who reported "more than 20,000." Instrument flying experience ranged from none to several thousand hours. Participants from several foreign countries also flew during the test.

Flights were conducted during both daylight hours and hours of darkness. Most of the approaches were in weather conditions above 1,500-foot ceiling and 5 miles' visibility, although a few pilots, particularly from NAFEC, had the opportunity to observe the systems under worse conditions. Several prolonged periods of unfavorable wind conditions made it necessary that only low approaches be made during those periods.

Aircraft types flown during the program were: Piper Tri-Pacer, Piper Apache, Piper Comanche, Beech Travelair, Beech Bonanza, Aero Commander, Mooney Mark 20-A, C-45, C-47, C-54, C-118, C-119, C-124, C-131, KC-135, B-47, SA-16, F-84F, T-33, Grumman TF, F9F, De Haviland Dove, Gulfstream, Electra, Constellation, and Boeing 707.

The briefing brochure and the oral briefings referred to the systems by code names rather than by manufacturers' or designers' names. Code names used were Tricolor, Mirror, Amber, Double-Bar, and Red-White for Westinghouse, Navy, USAF, Cumming-Lane, and RAE systems, respectively. During the early part of the test, each pilot was asked to make two practice runs before making a recorded run on each system. After the decision was made to retain only the Cumming-Lane and the RAE systems, each pilot was allowed up to four practice runs on each, with the requirement that each system be flown the same number of times. Most of the recorded runs were made during straight-in approaches from the outer marker (4.3 nautical miles).

In addition to the mass of data collected from the runs, special measurements were made to investigate the effect of visual aids upon touchdown dispersion, and the amount of time required for a pilot to maneuver the aircraft to the glide path after being deliberately displaced

therefrom under hooded conditions. The first of these touchdown dispersion measurements was made using a highly qualified pilot in an F9F-8T. A series of landings was made without visual glide path assistance, and the touchdown points recorded. The sequence of events was repeated with both the RAE and the Cumming-Lane devices switched on. The second special test used pilots who were familiar with both the RAE and Cumming-Lane systems. One pilot in a C-131B (Convair 340) and another in an Aero Commander were used as subjects. A series of alternately high and low deviation of the same magnitude for each run was set up, with the pilot hooded and aircraft positioned by the observer on the centerline extended. Precision approach Radar (GCA) gave a mark at 3 miles from the threshold. The subject pilot then looked out as the observer started a stop watch. The pilot in each case was briefed to interpret the signal and maneuver the aircraft to the glide path as quickly as possible, at which time the watch was stopped. It was recognized that normal procedure, if below the glide path, is not to climb, but to level off until the glide path is intercepted. For this test, however, the pilot was asked to find the glide slope from both high and low positions.

Data Reduction

Subjective data from pilot reaction questionnaires were tabulated (Appendix II). Most responses could be made by means of check marks. Questions which invited comment were reviewed and selected comments are included elsewhere in this report.

Some of the airline pilots flying Boeing 707 aircraft were unable to submit complete questionnaires due to the pressure of their regular duties. They submitted brief impressions, however, and because of the importance of selecting a device which can be used by large jet aircraft as well as smaller, more maneuverable craft, their preferences are included in the tabulated data.

The time required to maneuver to the glide path by the two selected pilots referred to under "Data Collection," above, was recorded in tabular form and is included as Appendix III.

Recording of touchdown dispersion was so inconclusive that further efforts in this direction were not pursued. The pilot stated that even though he used the angle-of-attack indicator, no two approaches were exactly alike, and the visual glide path systems had no bearing on his actual touchdown point. He did state, however, that the indicators enabled him to establish his desired angle of attack sooner and maintain it with fewer adjustments until he was ready to transfer his attention to the actual flare and touchdown.

Sensitivity curves comparing three systems which were visible at long range (USAF Amber, Cumming-Lane, and RAE) were prepared by Mr. J. C. Morrall of the Royal Aircraft Establishment. The curves represent the upper and lower limits of the area within which it is possible to receive an indication of being on the glide slope. These data are shown in Fig. 13.

Reduction of theodolite film was accomplished by film readers punching the data points on IBM cards. The cards in turn were used to prepare a program for the NAFEC IMB 709 computer. Tabular data produced by the computer then were plotted as graphs (Figs. 14 through 18). Computer data sheets are attached as Appendix V.

Data Analysis

Pilot Reaction questionnaires were analyzed to (1) investigate the attitude of individual pilots with respect to the need for visual glide path indicators, and (2) to determine which system in the NAFEC evaluation was preferred by the most pilots. An example of the questionnaire, with tabulated responses, is attached as Appendix II.

The questions for the most part were designed to be answered by a check mark in an appropriate square. This was done to allow the subjects to complete the form in a minimum of time. Even so, some of the participants, particularly Boeing 707 pilots, were pressed for time and consequently recorded their impressions in quite condensed form and mailed them in upon return to their base. Also, a group of 12 pilots from one organization whose questionnaires got lost in transit recorded their impressions in composite form. These results are not included in the tabulated data. Of the more than 100 subjects who participated, questionnaires were returned by 62. Abbreviated comments were submitted by 17 others. The consolidated results herein include replies from participants who flew during the early phase, when all five systems were in the program, as well as from those who flew on the two systems retained for the second phase of the evaluation.

The decision to concentrate the task effort on the RAE and Cumming-Lane systems was based on flight experience of the task manager and the participating pilots. At the time the decision was made to limit the task, analysis of almost 400 runs (flown during check flights, demonstrations, and actual task flights) indicated that the three systems described below would not provide adequate guidance for overall general use.

The mirror system green datum lights were visible at five miles under normal night conditions and at about three miles in daylight. The reflected source light required for guidance, however, was usable for only about two miles at night and a lesser distance in daylight. During one night flight, moisture on the mirror caused a degradation of the glide slope signal to the point where it was unusable. Also, unless the aircraft was at the proper altitude at acquisition range, there was no indication as to which way to fly (up or down) to intercept the glide slope.

In the case of the USAF interim system, the green datum lights were visible at distances beyond the outer marker, even in daylight. Again, however, the amber source light was not visible until about one and one-half nautical miles from the threshold in daylight and about two and one-half nautical miles at night. This system has a serious defect, moreover, in the quality of guidance. Because of the short distance between the source light and datum bars (60 feet) the sensitivity of the system was so poor that a large change in altitude produced little or no change in the position of the source light with reference to the green datum bars. A plot of the sensitivity curve shows, in fact, that it is possible to receive an indication of being on the glide path at an altitude of only 40 feet above ground, three nautical miles from touchdown (see Fig. 13).

The Westinghouse Tri-Color system was effective at night in clear weather. It has been seen at the outer marker (4.3 nautical miles) under those conditions, and the guidance received was good. In daylight, however, the units were seldom seen by pilots until the aircraft was practically over the threshold. Several pilots called to verify that the units were not turned on, although they were operating properly. Also, color definition deteriorated when precipitation was present or when moisture collected on the lens. This latter condition was noted after particles of snow had blown against the lens and melted there. Some pilots expressed confusion about the $1/2^{\circ}$ difference between the glide paths of the two units, even after they had been briefed.

Since evaluation of the three systems mentioned above was discontinued, the discussion of the pilot responses will deal only with the Cumming-Lane and RAE systems.

The first three questions concerned the need for Visual Glide Path Indicators. There were 34 responses indicating that under clear

daylight conditions such devices are unnecessary. Twenty-four, however, indicated that they are desirable and two necessary. The largest number of responses (47) indicated a necessity for visual glide path guidance under night and reduced visibility conditions. The same number indicated that guidance is desirable under night, clear, conditions with a well lighted foreground. Forty-one indicated that they felt guidance necessary under night, clear conditions with an unlighted foreground.

One pilot, an executive of a local service airline, maintained that visual glide path devices are completely unnecessary and that while "nice to have," the money would be better spent on other airport lighting developments.

The question as to type of airport to be equipped with visual glide path indicators drew varied responses with 47 expressing the opinion that airports surrounded by unfavorable terrain should be given first priority. Of interest is the fact that city terminals received only five first preferences, with at least one comment added that the choice was made from the noise abatement standpoint.

Of the two systems finally considered, the RAE was felt by 30 subjects to wholly satisfy the need for guidance and 28 to partly do so. The Cumming-Lane system was considered wholly adequate by 15 and partly adequate by 41.

The next 14 questions concerned various aspects of individual systems which the subjects were asked to compare. Of the 14 aspects considered, the RAE system was felt to be better in 11. The Cumming-Lane system was considered better in 2, and they were considered equal in 1.

Only a few pilots commented on inherent dangers. A few considered that all systems could cause a fixation, with the pilot neglecting his normal flight instruments. Some comments were made regarding the possibility of misinterpretation of the Cumming-Lane bars upon breaking contact from an instrument approach since the position of the white bar of lights in relation to the glide slope is the reverse of the position of the ILS glide slope needle. A few pilots mentioned that the red color of the RAE system might be mistaken for obstruction lights. One pilot made the comment that dependence upon visual glide path indicators might eventually impair the natural judgment of pilots to the point where good approaches could not be made into fields not equipped with indicators.

With regard to instrument reference during a normal approach on the Cumming-Lane system, 25 pilots said less attention was required, 27 said the same amount of attention was required, and 5 said more was required. For the RAE system, the results were: less - 26, same - 32, and more - 3. One pilot indicated more attention to instruments was required on all systems but attributed it to unfamiliarity with the aircraft.

When asked about their instinctive feeling about height during the last half-mile of the approach, 9 pilots felt the Cumming-Lane system brought them in too high, 39 said about right, and 4 felt too low. For the RAE system, 6 felt too high, 49 about right, and 1 too low.

After considering all aspects of each system, pilots were asked outright which one was preferred. Two pilots said that either the Cumming-Lane or the RAE system would be acceptable. Fifty-eight replies to this question were received. The RAE system was preferred by 36 pilots and the Cumming-Lane by 22. In addition, the abbreviated comments received indicated a preference for the RAE system by 12 pilots, with 5 pilots in favor of the Cumming-Lane system. Counting these latter opinions, the final tally is in favor of the RAE system, with 48 for RAE and 29 for Cumming-Lane.

Pilots generally considered the briefings satisfactory. Two pilots flew on the systems with no formal briefing other than the brochure.

Adjustments in intensity were at the discretion of the pilot. In daylight, full intensity was required on all systems. A common complaint was that the amber in the Cumming-Lane system was not equal to the white in brightness. After a change in lamp type, described later in this report, this condition was corrected. Background color and ambient brightness was a factor in both the RAE and Cumming-Lane systems' effectiveness. The daytime acquisition range of both systems decreased noticeably when the ground was snow-covered. With no snow, each can be seen at the outer marker (4.3 nautical miles) with the sun shining. Under sunlight and snow conditions, the range is decreased to about 3.5 nautical miles. Under these conditions, interpretation of the Cumming-Lane signal is somewhat easier as reported by pilots. The white of the RAE lights is harder to see and the red seems to reduce in intensity. At night, when reduced intensities were required, the white of the RAE system took on a slightly orange cast,

and some pilots stated they were not sure whether they were in the white sector of a particular bar or whether they were entering the transition zone of the pink. Experience should eliminate this problem, but another solution proposed later in this report is to substitute a blue-white filter for the clear filter.

When asked to judge the quality of their own approaches, 27 pilots said they made good approaches with the Cumming-Lane, while 32 judged their approaches as average. With the RAE system, the trend is reversed, 38 considering they made good approaches and 25 stated their approaches were average. Bad approaches were reported by 2 pilots on Cumming-Lane and by 3 on RAE. Their comments indicated, however, that gusty winds, tailwind, or crosswind conditions were the cause factors.

Operators of large jet aircraft have expressed interest in visual glide path indicators. Accordingly, a special look was taken at the preferences of Boeing 707 pilots and KC-135 pilots. Of 12 pilots in the category, the RAE system was preferred by 9 and the Cumming-Lane system by 3.

In addition to collecting pilot reactions, objective data were collected to measure system performance. Figures 14 through 18 represent the mean glide slope flown by all pilots and all aircraft types recorded. With respect to the two systems retained for the complete period, the recorded data does not reveal a significant difference in the aircraft trajectory (Figs. 17 and 18). It should be noted that gross errors, which will be discussed later, were eliminated in the plotting of these data. It is of interest to note that the mean glide slope on both the RAE system and the Cumming-Lane system is slightly high, but fairly constant. This might be explained by the unusual number of days during the evaluation period when winds were strong from the northwest. Many pilots commented on the downwind conditions, with attendant difficulties in getting down to the glide path. These difficulties are verified by the recorded data.

The computer data sheets (Appendix V) show the points at which the lights were visible, where guidance was received, and where guidance was lost, as reported by the pilots. These points are designated "Mark 1," "Mark 2," and "Mark 3," respectively. The only one of these points shown on the plots is Mark 3, distance from touchdown at which guidance was lost. The average distance at which

pilots reported losing guidance on the Cumming-Lane system was 2,495 or 1,495 feet from the threshold. The original computation from the machine showed that some erroneous values were included which affected the system performance summary, as shown on RAE distance Mark 3 to touchdown. The values were recomputed and the error was disregarded (error was Run 13 shown on sheet E-2, page 24 of Appendix V). The recomputed average distance from touchdown at which guidance was lost is 727 feet.

The recorded data do not show a significant difference in the distance Mark 1 to touchdown between the RAE and Cumming-Lane systems. If circling approaches are not considered, it is significant that the distances Mark 1 to touchdown are fairly consistent, even though day and night runs are not separated.

It is of interest to note the distance Mark 1 to Mark 2 (sheets D-2 and E-2, Appendix V). This represents the distance flown on each run after the pilot reported lights in sight and before he reported that he was able to determine his position with respect to the glide slope. For the Cumming-Lane system, out of 29 runs recorded, only one pilot reported guidance as soon as he saw the system (run 6, sheet D-2, Appendix V). Out of 22 recorded runs (run 13 omitted) on the RAE system, four pilots reported guidance immediately upon seeing the lights (runs 7, 19, 20, and 23). This would appear to verify the opinion expressed by a majority of pilots that the RAE system provides a quicker indication of position.

Visual examination of the computer data sheets revealed some obviously inaccurate values for maximum vertical deviations. As stated before, these gross errors were disregarded during the plotting of the mean glide slopes, but they were included in the machine computation of system performance, as shown on sheets D-6 and E-5 of Appendix V. A recomputation was run which revealed the following results:

<u>Cumming-Lane System</u>

Mean deviation in the vertical plane (V-MN) 7.390 feet. Standard deviation in the vertical plane (SD-V) 115.692 feet. Maximum deviation in the vertical plane (V-MAX) 222.709 feet. (Recomputation did not include bands 7, 10, 17, and 35.)

RAE System

Mean deviation in the vertical plane (V-MN) 13.080 feet. Standard deviation in the vertical plane (SD-V) 65.015 feet. Maximum deviation in the vertical plane (V-MAX) 157.282 feet. (Recomputation did not include band 2.)

It should also be noted that none of the computation included band 1, as part of this band was actually beyond touchdown.

Measurements taken of time required for a pilot who is experienced on both systems to locate the glide slope from a deliberately displaced position were inconclusive (Appendix III). If any conclusion is to be drawn, it is that with training and experience on both systems, a pilot can locate the glide slope with equal facility, when he is making a conscious special effort to do so, particularly at a medium distance such as used in this test (3 nautical miles).

Maintenance Considerations

Navy Mirror: The mirror system for the most part is a rugged piece of equipment. It is easily transported and can be set up quickly. The very heart of the system, however, is the mirror itself, constructed of an optically perfect concave piece of glass. Although no factual information resulted from this test as to its ability to withstand various weather phenomena, there are serious doubts that for common use such a device would remain unscathed in a sandstorm, such as often occurs in certain sections of the United States. Such storms have been observed to etch automobile safety glass and remove paint from vehicles. Also for shore use, a means would have to be developed to keep the glass dry. Moisture on the mirror during one night's flight degraded the glide slope signal to the point where it was unusable.

USAF Interim Mirror (Meatball): No significant maintenance problems with the equipment were observed.

Westinghouse Tri-Color: No significant maintenance problems were evident with this device. One lamp burned out early in the program, but it had been used in earlier tests at the Technical Development Center and records are not available to show how much time it had operated.

Cumming-Lane: This system posed the most problems from a maintenance standpoint. During the early weeks of the test period, several severe windstorms occurred. Peak gusts of over 70 knots were encountered and winds of 35 - 40 knots were common. Two poles were blown down during the period, and more recently, a vehicle towing a smoke generator, in connection with another project, ran into one of the guy ropes causing the pole to fall over. On two of these occasions the pole had to be taken into the shop for repair thus detracting from the system for periods up to two days. The poles were guyed with nylon, to minimize interference with the ILS glide slope. The elasticity of the nylon provided some protection against buffeting, but the lamp holders would still get out of alignment. This required use of a ladder truck to tighten and adjust the lamp holders; when the ground is soft, this poses a problem in getting in to the poles. One other problem which arose was warping of the poles. A bent pole would cause the axis of the lamp to be aimed in a direction other than the optimum. Lamp adjustment was simplified in such cases by use of a simple device incorporating a clinometer level which was adjustable to a desired angle of elevation and which was made so as to fit against the face of the lamp. The lamp holder was adjusted to center the bubble in the clinometer, and by use of a gunsight arrangement the lamp could be aimed laterally. The adjusting device was fabricated by NAFEC, and showed much promise as a simple way to check airport approach lights as well as the lights in the Cumming-Lane system.

RAE System: The RAE system, as a whole, was almost completely trouble-free. One lamp failed early in the test, and was sent to the National Bureau of Standards for examination. It is suspected that the lamp may have been damaged in shipment or in installation. In the units made by Thorn Electrical Industries, Ltd., the British manufacturer, it has been noted that the red filtering material has split on a number of the filters and separated from the glass. This has had no apparent effect on the signal, but the Sylvania Electric Products Co. (the company authorized to produce the units in the United States) proposes to incorporate the red color in the glass itself, to eliminate this problem. A deficiency in the design of the lamp holder was evident in the large number of small bolts (12) required to hold the assembly together. This minor deficiency was more than offset by the ease with which a complete lamp assembly could be replaced in case of failure. The sealed-beam lamp was secured in a prefocused position in the holder, which is attached to the optical bench framework by 4 Dzus fasteners shaped like wing nuts. Positioning lugs on the frame fit into holes on the lamp assembly so that it can be installed in only the correct position.

A defective lamp can be removed and replaced in about one minute. The faulty assembly can then be removed to the shop, the sealed beam unit replaced and focused, and reassembled for future use. The buffeting effect of the winds during the test period, coupled with some shifting of the concrete bases, under the units, caused some of the units to get out of adjustment. This situation is quickly and easily corrected by using a bubble sextant to sight on the edge of the white beam and measuring its angle of elevation. A sample series of sextant sightings is included in Appendix IV. After the sightings have determined the degree of correction required, the adjusting screw is turned in the proper direction, using the click stop feature to measure the correction applied. This is an ingenious feature which provides a noticeable "click" as the screw is turned through each minute of arc. Each revolution will cover five minutes of arc. This feature may also be used in the initial adjustment of the units, after first leveling the optical benches with an ordinary spirit level.

Other Considerations

Aside from operational and maintenance features, other factors have been considered in this evaluation.

1. Cost:

Hardware costs for each system are approximately as follows (excluding current regulating equipment, selector switches, and brightness controls):

a. Navy Mirror: Without the diesel generator, the mirror system costs approximately $7,500.00.

b. USAF Interim Mirror System: This equipment was fabricated locally using equipment on hand, for the most part. Material (including lamps, holders, transformers, and so forth) and labor would cost approximately $750.00.

c. Westinghouse Tri-Color: Unit (less lamp and base) lists in the manufacturers' catalog at $930.00 each. Net price to the government is less, however. Total cost for complete system is approximately $1,000.00.

d. Cumming-Lane: Approximate cost, including labor and materials, for poles, lamps, holders, transformers, and so forth, is $1,041.00.

e. RAE System: Cost of a complete system, consisting of 12 units, complete with lamps (lamps manufactured in U. S. by Sylvania) is $5, 700. 00. Since operating experience with the Sylvania lamps was lacking, NAFEC purchased 36 replacement lamps with holders, costing $1, 638. 00, to provide 100 per cent backup. Operating experience has shown that this degree of backup is unnecessary. The Sylvania Electric Products Co. has estimated that if quantity production methods were employed, the cost could be reduced by at least 25 per cent.

f. Installation expenses are dependent upon many factors, such as local labor costs, terrain, type of soil, distance between the system and control point, and availability of existing runway ducts, selector equipment and current regulating equipment. Estimated installation costs for the NAFEC tests, if only one system had been included in the contract, are approximately as follows: Navy Mirror, $2, 500; USAF Interim Mirror, $3, 000; Westinghouse Tri-Color, $2, 500 (this could be reduced to approximately $1, 000 by connecting the units to the runway edge lighting circuit. A control unit in the tower for turning the indicators off when the edge lights are on would add about $500 to the cost. Intensity control is not required, as it must run on maximum intensity to be useful); Cumming-Lane, $5, 000; and RAE, $5, 000. These estimates are all based on a distance of approximately 1, 000 feet between the power source (and control point) and the touchdown area.

2. Obstruction Potential:

Obstruction potential of each system was included in the questionnaire. In addition to pilot preferences, it should be noted that the USAF Interim system and the Navy Mirror system were installed closer to the runway and were constructed of more substantial materials than any of the others. The RAE units were installed at NAFEC so that the tops of the units were below the elevation of the runway centerline. If the adjacent grade does not permit this, it should be noted that the maximum height of the unit, from base frame to top of the face plate is only 14 inches. The design of the optical bench and cover is such that the whole assembly would flatten instantly if struck by a vehicle or aircraft. The Cumming-Lane poles are located in such a position that the chance of being struck is remote. In Australia, there have been no accidents over a two-year period in which an aircraft could have collided with the poles. The Westinghouse Tri-Color units pose no particular problem because of their low height (16 3/4 inches).

3. Electronic Interference:

Electronic interference was carefully investigated to determine whether any system would affect the ILS glide slope. FAA flight inspection aircraft ran a complete ILS flight check with the components of the various systems in place and dismantled. Results showed that no single system nor the combination of systems caused electronic interference.

4. Brightness:

Brightness control was available on all systems, and changes were made when requested to accommodate pilot preferences. Background color of the local terrain in daylight was mentioned frequently by pilots flying the Cumming-Lane system as making the amber color difficult to distinguish. At night, some pilots stated that there was insufficient contrast between amber and white at higher intensity setting. Accordingly, three weeks before the end of flight testing, the original PAR 56, 300-watt lamps on the poles were replaced by PAR 56, 250-watt 12.5 volt airport approach lamps. The intensity of this lamp is 75,000 candles before filtering with amber glass, as compared with 28,000 candles for the original lamps. Effective intensity of the new lamps, when filtered by the amber glass is 35,000 candles. This change was observed to brighten the amber lamps and to give them a more nearly equal intensity to the white lights. In the case of the Westinghouse Tri-Color, maximum intensity was required at all times, and in daylight, the units could be seen only when approaching the threshold. Many pilots never did see the lights in daylight, and only one run was able to be recorded on the system in daylight. The brightness control, when using the RAE system, was always at maximum intensity in daylight but could be reduced at night. Reduction of the current had the effect of reducing the white color slightly toward orange. At longer ranges (3 - 5 miles), this effect injected an element of doubt into some pilots' minds as to whether they were beginning to move into the pink transition zone. Additional experience on the device can overcome this problem, but it might also be advisable to place a blue-white filter in front of the lower part of the lamp, rather than a clear filter. This would cause the white beam to appear whiter when the lamp is operating at a reduced intensity setting.

5. Fail-Safe Features:

Fail-safe capabilities of the systems vary. The tri-color units are flashed by means of a motor driven cam-operated shutter. On

one occasion, power failed in the motor circuit and the motor stopped. No light was emitted, even though the lamp was energized. This was apparently due to the shutter stopping in such a position as to block the beam. Since they are used in pairs, there is still a unit operable in case of failure of one. The Mirror system can provide guidance in case of individual lamp failures, and no problems of failing unsafe occurred. The Cumming-Lane system was successfully flown on only one-half a complete system, with all components on the left hand side of the runway out of commission. During times when individual amber lamps were either down or badly out of adjustment, guidance was available. Comments relative to the Mirror system also apply to the USAF Interim system. The RAE system might be said to be the least vulnerable to failure which could cause an unsafe condition. Since the complete array contains 36 lamps (three in each unit), failure of a single lamp is hardly perceptible. A failure of a unit, a complete half bar, or all units on one side of a runway will not decommission the system, because the color relationship between the remaining units will still provide glide slope information, since alignment is not a feature of the system. Finally, the most severe type of breakdown might be considered the complete failure of all units in either the upwind or downwind bars on both sides of the runway. In this event, a pilot could still avoid undershooting by remaining above the red signal of the operative lamps. In this test, it was found possible to fly the pink sector of a bar of light. Thus, a safe approach could be flown using this technique.

CONCLUSIONS

Based on the results of this evaluation, it is concluded that:

Presentation of glide slope information by visual means is entirely feasible.

Both the Australian Cumming-Lane system and the British RAE system are capable of presenting such information at distances up to 5 miles in daylight and at greater distances at night.

There is no significant difference between the two systems with respect to ease of maintaining the proper glide slope by the pilot.

The RAE system is preferred by the majority of pilots who participated in the evaluation.

Objective data show that position recognition by pilots is quicker on the RAE system than on the Cumming-Lane system.

Objective data verify pilot opinion that the RAE system gives guidance closer to touchdown.

The initial cost of the complete RAE system is higher than for the Cumming-Lane system, but maintenance is less of a problem than with the Cumming-Lane system. Further, airport operators who wish to do so can reduce the cost of the RAE system by using less than the full complement of 12 RAE units and still provide visual glide path guidance to aircraft.

RECOMMENDATIONS

Based on the results of this evaluation, it is recommended that:

The RAE Visual Glide Path Indicator, consisting of 12 RAE units, be adopted as the United States national standard.

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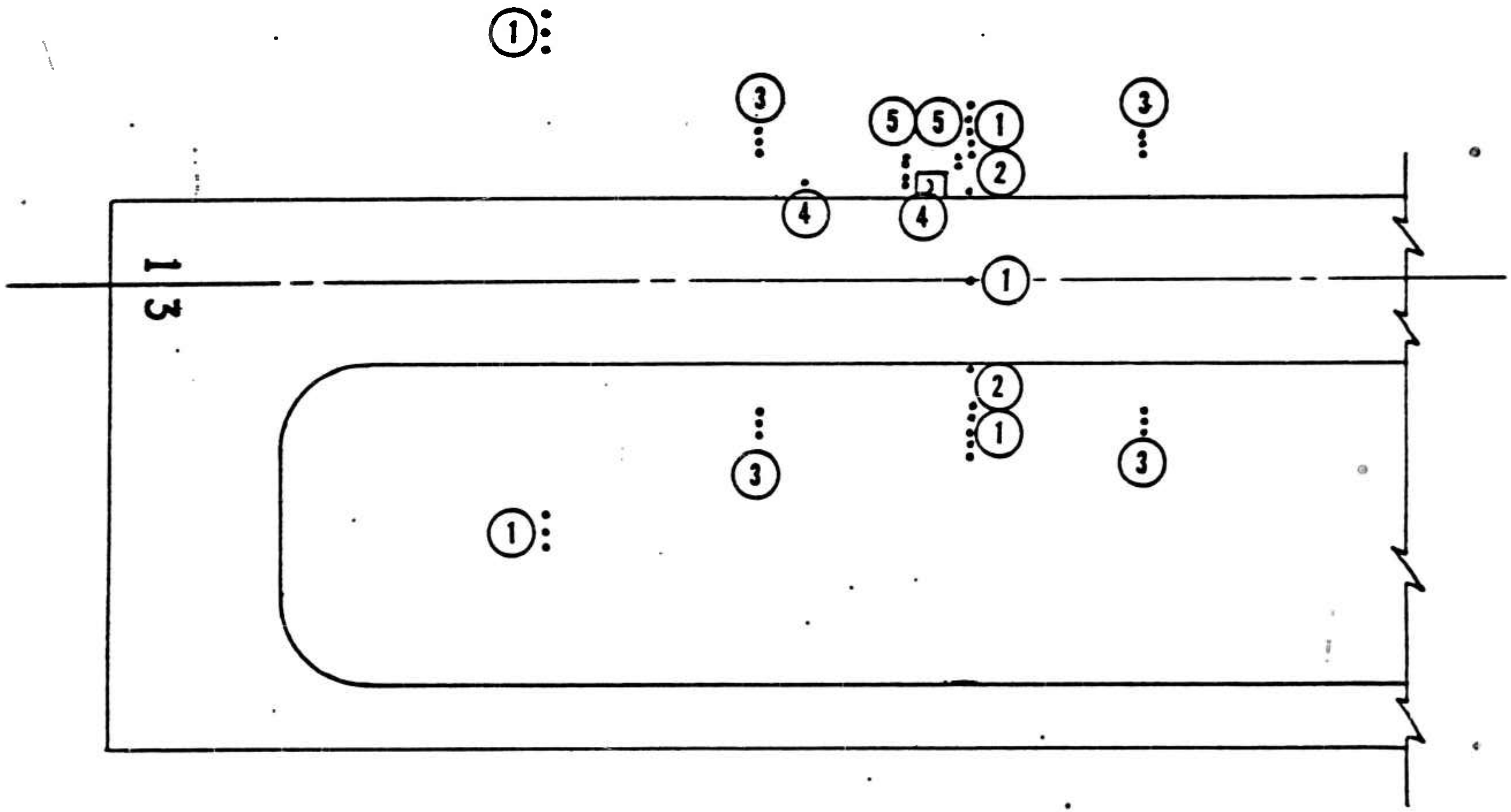
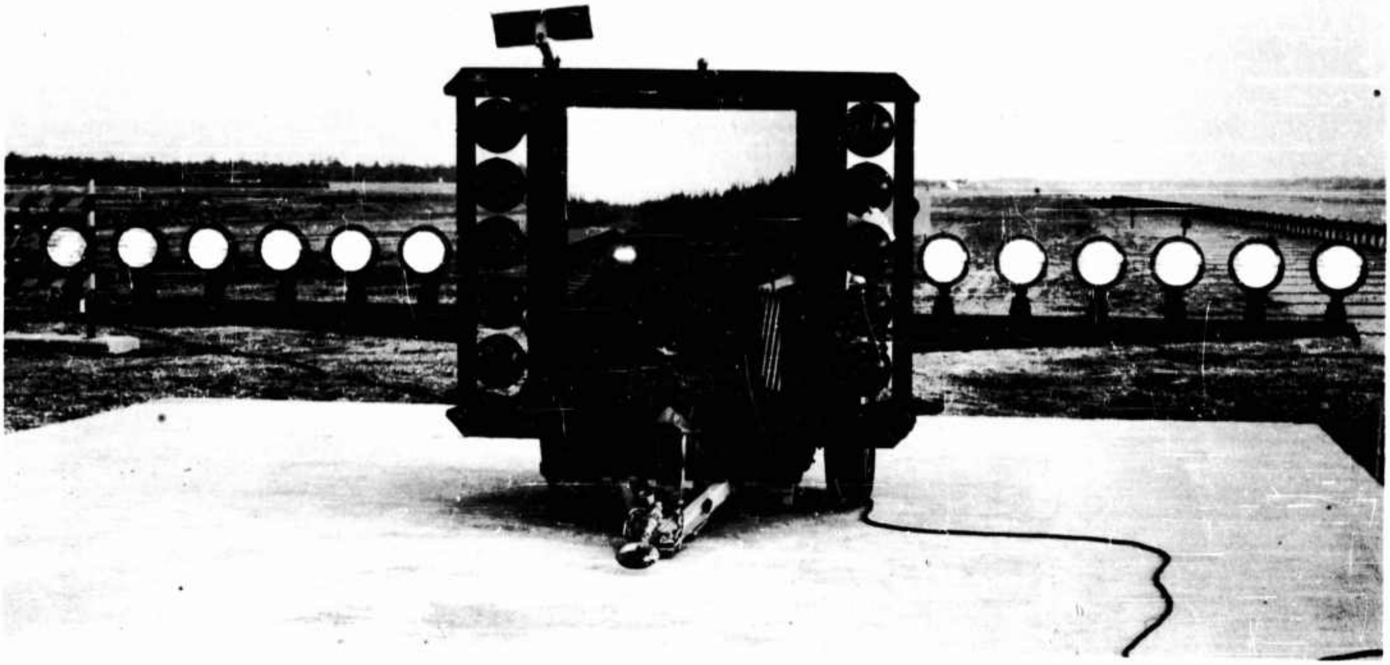


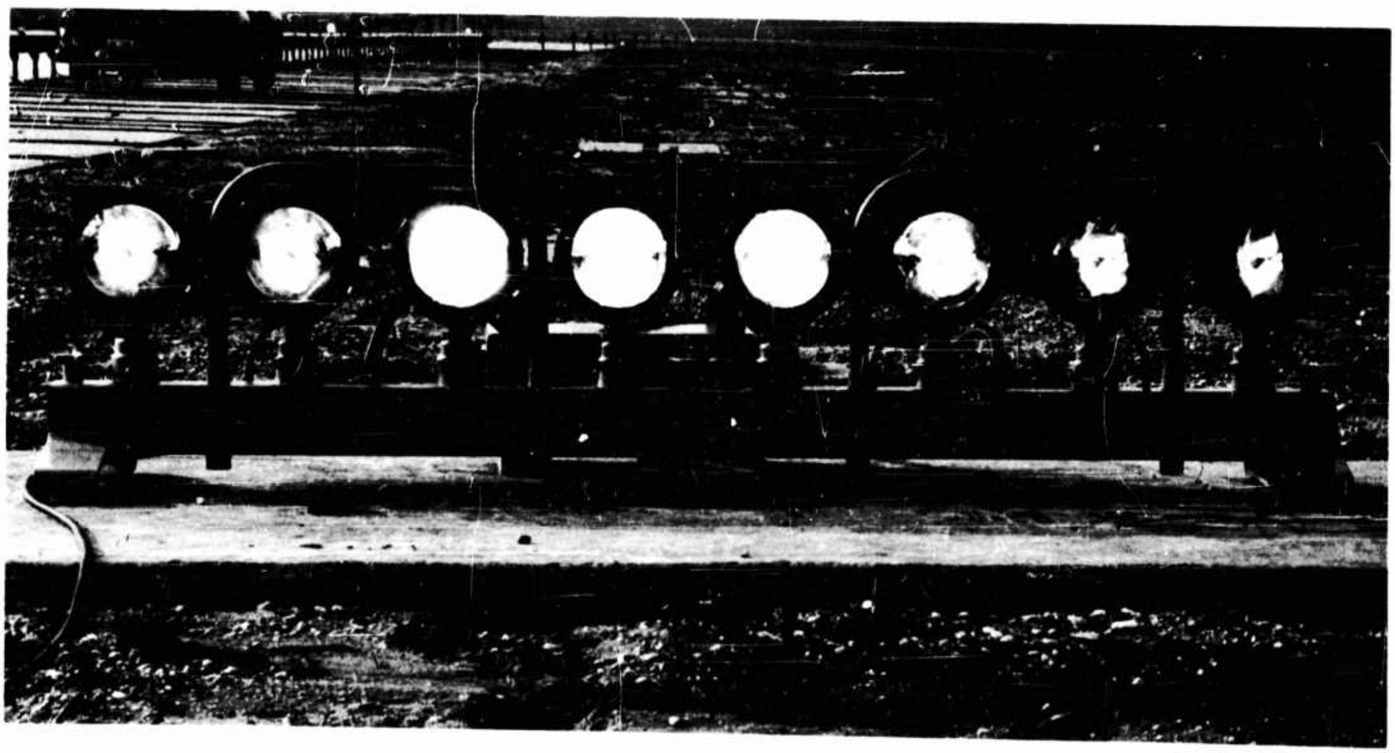
CODE

1 - CUMMING-LANE COMPONENTS
2 - TRI-COLOR PROJECTOR
3 - RAE UNITS
4 - MIRROR SYSTEM
5 - USAF INTERIM SYSTEM

FIG. 1 LOCATION OF SYSTEMS ON RUNWAY 13.



A. TRAILER-MOUNTED MIRROR



B. AMBER SOURCE LIGHTS

FIG. 2 NAVY MIRROR SYSTEM

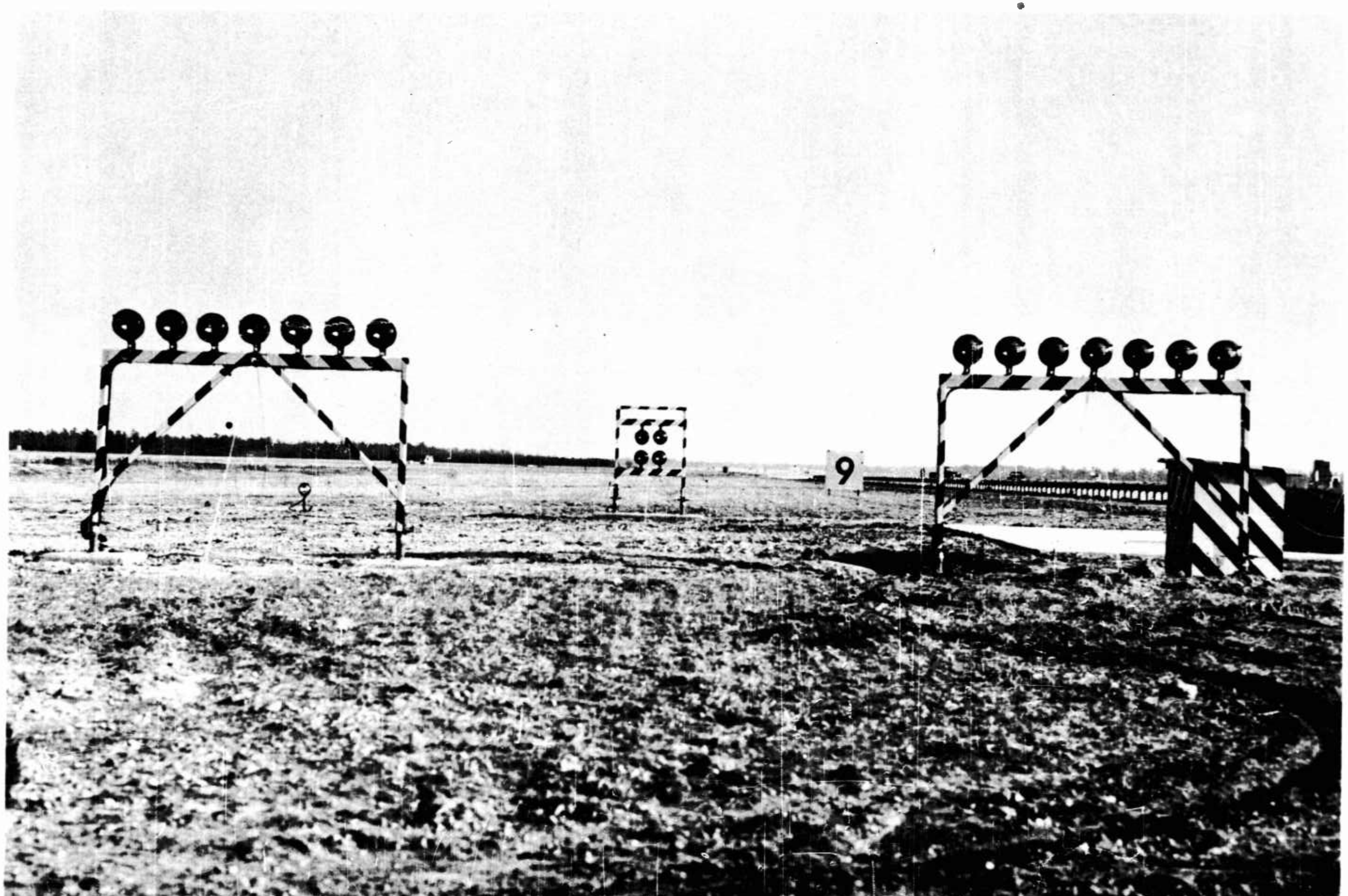


FIG. 3 USAF INTERIM SYSTEM

FIG. 4 WESTINGHOUSE TRI-COLOR UNIT

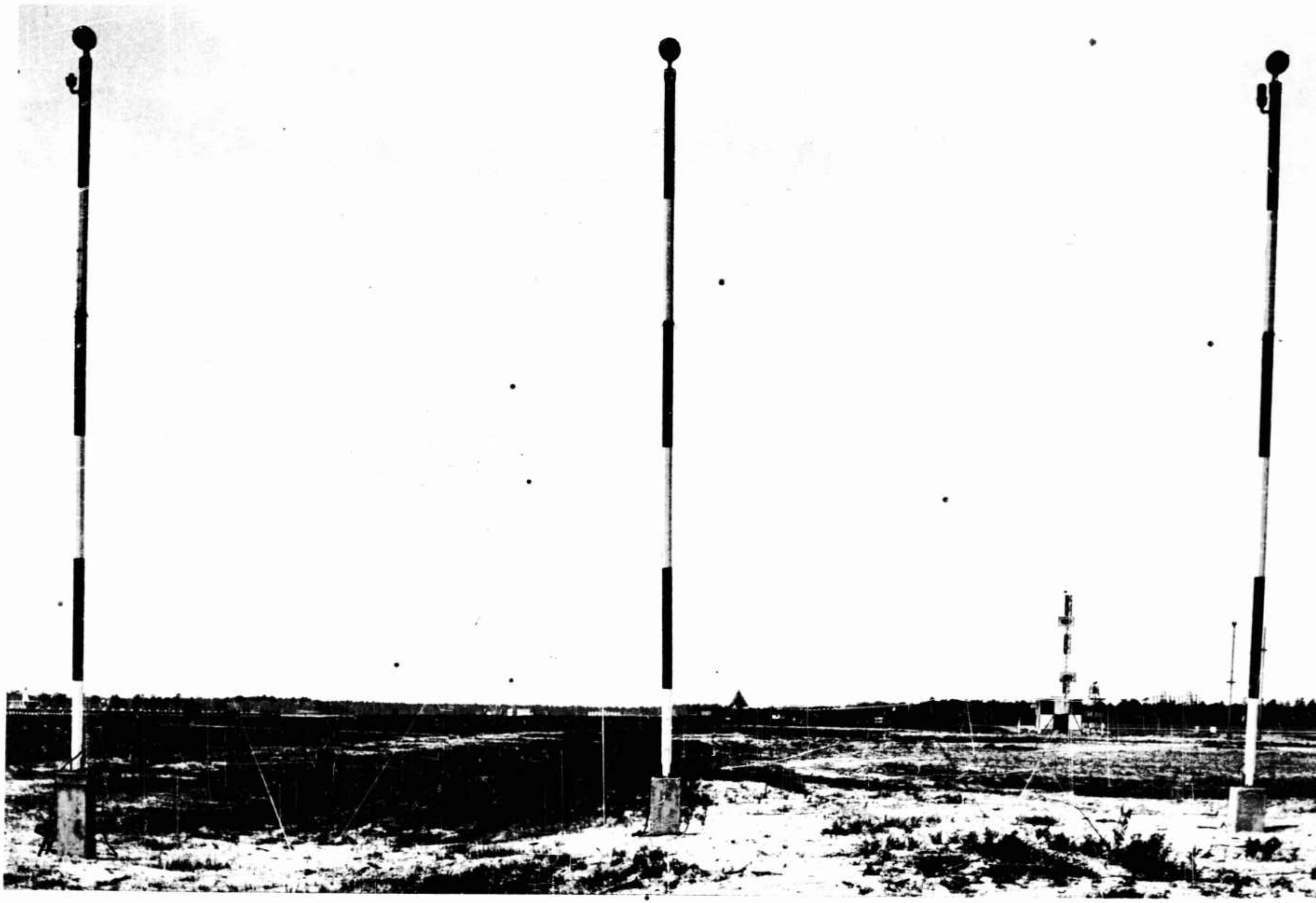


FIG. 5 CUMMING-LANE POLES

FIG. 6 CUMMING-LANE GROUND LIGHTS

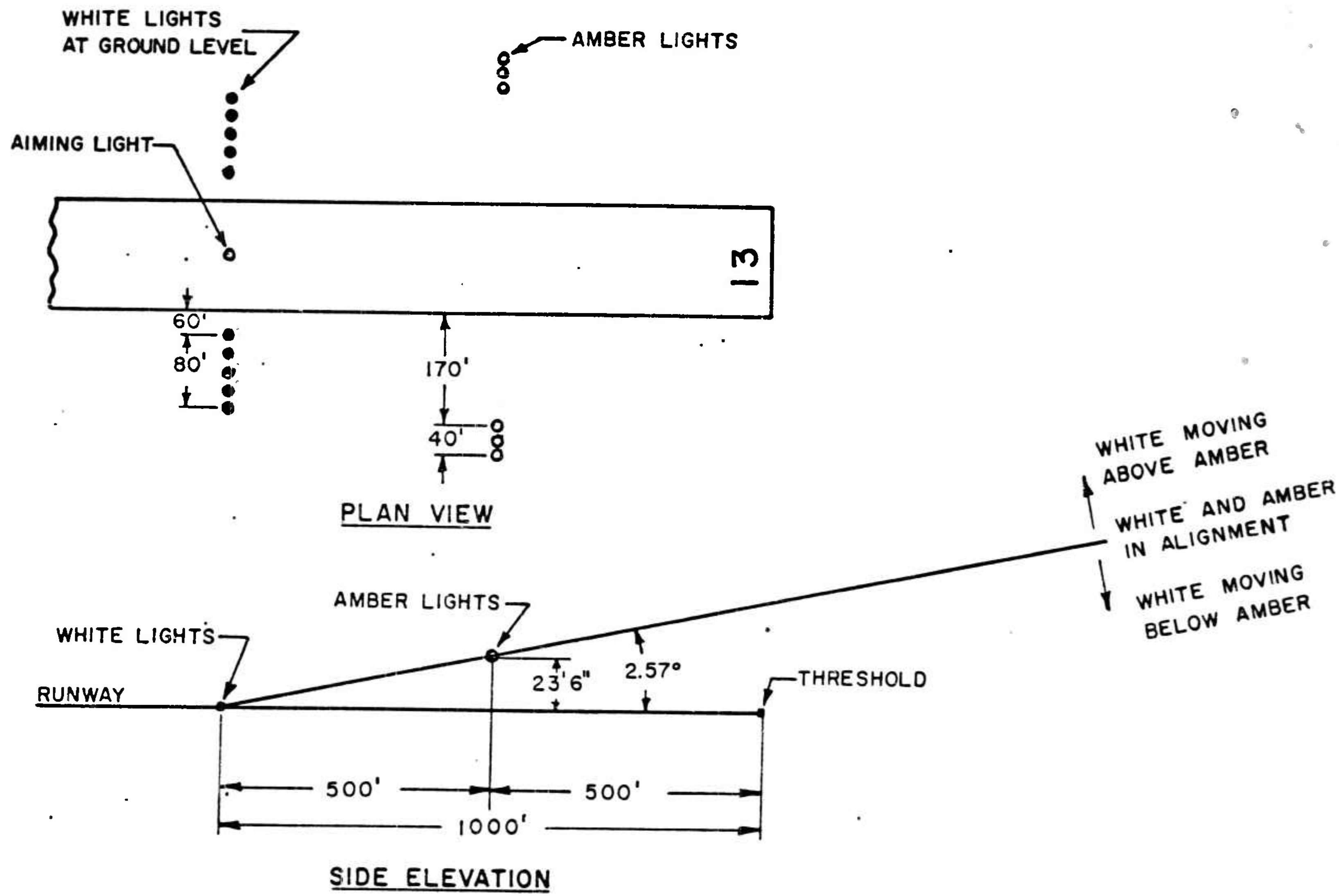
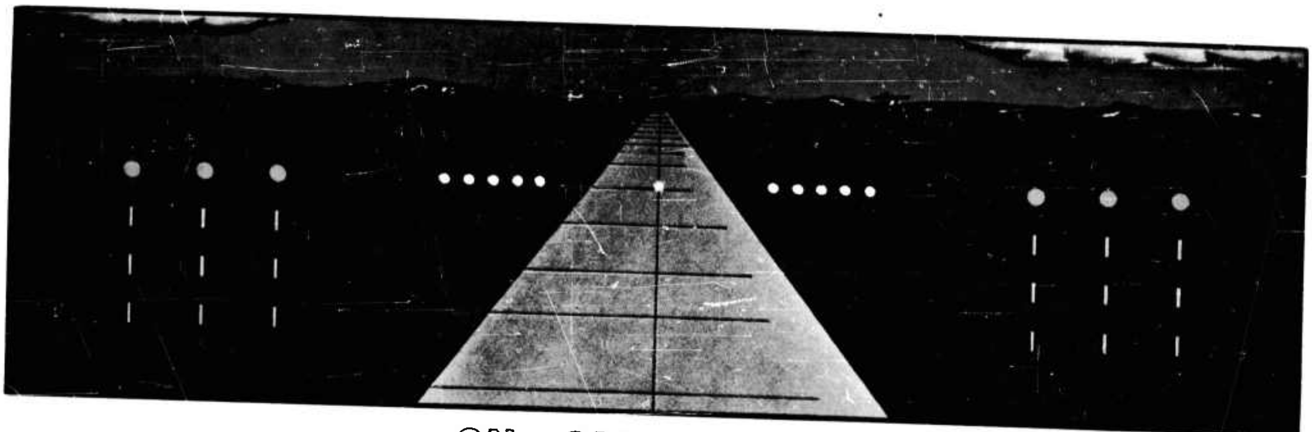


FIG. 7 DRAWING OF CUMMING-LANE SYSTEM

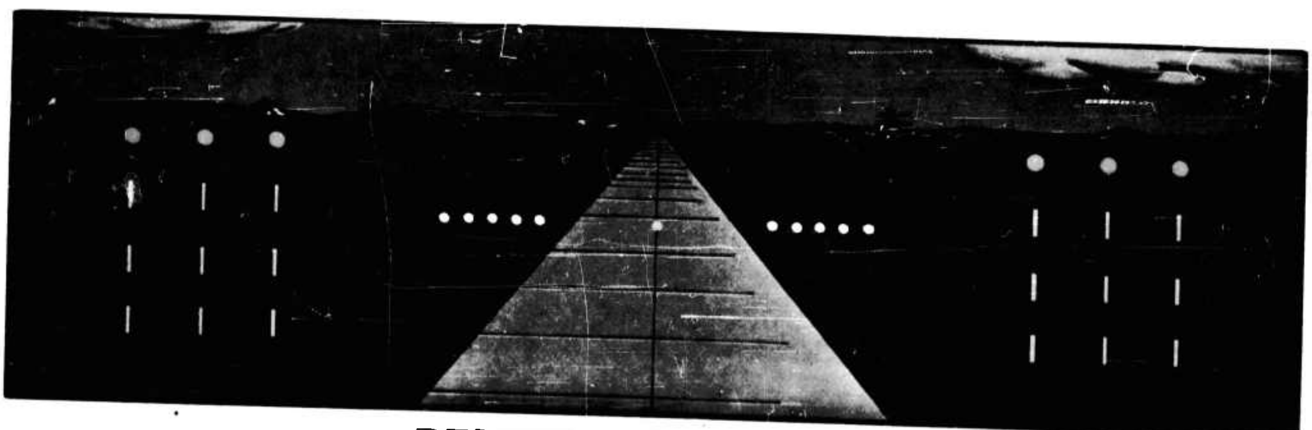
DOUBLE BAR SYSTEM

(CUMMING - LANE)

ABOVE GLIDE PATH



ON GLIDE PATH



BELOW GLIDE PATH

FIG. 8 COCKPIT VIEW OF CUMMING-LANE SYSTEM

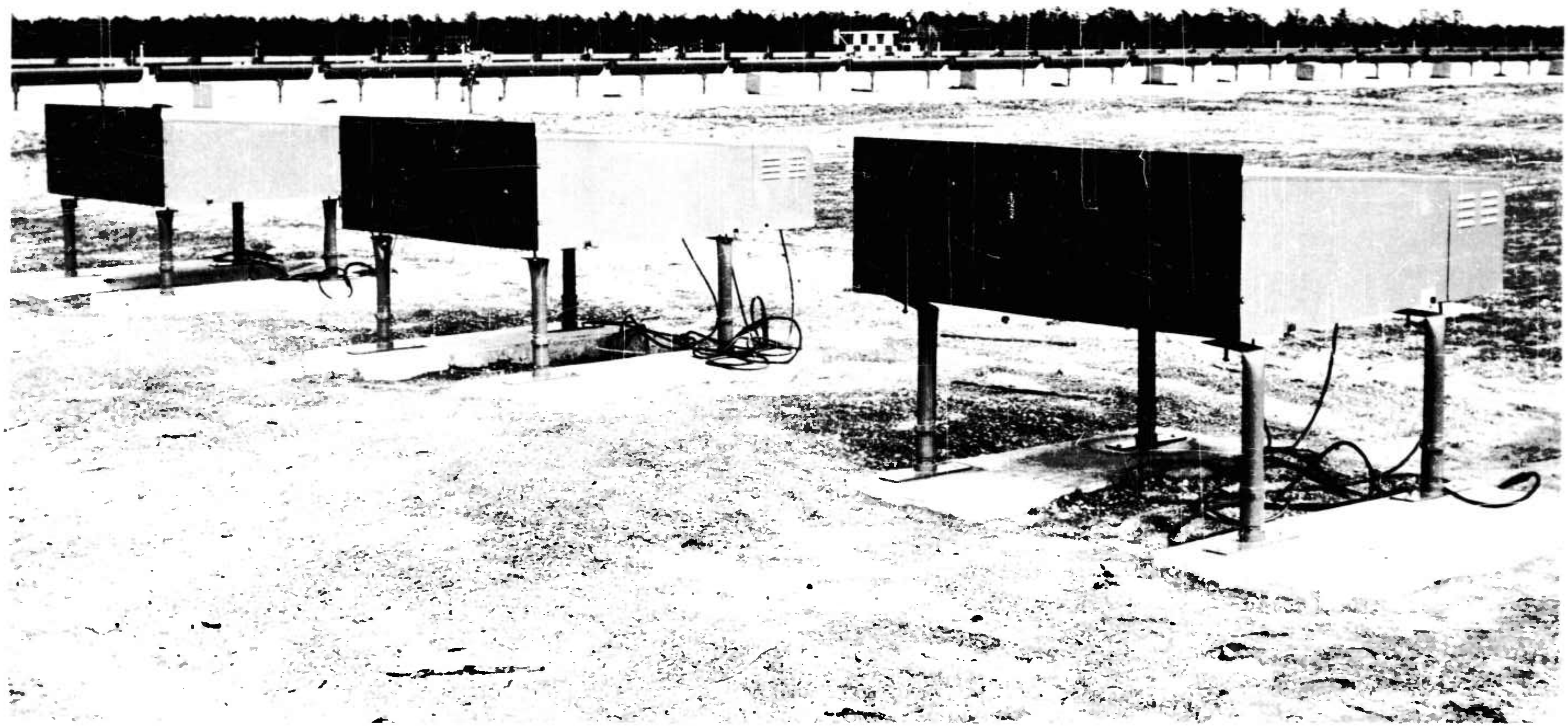


FIG. 9 R.A.E. UNITS

FIG. 10 OPTICAL BENCH IN R.A.E. UNIT

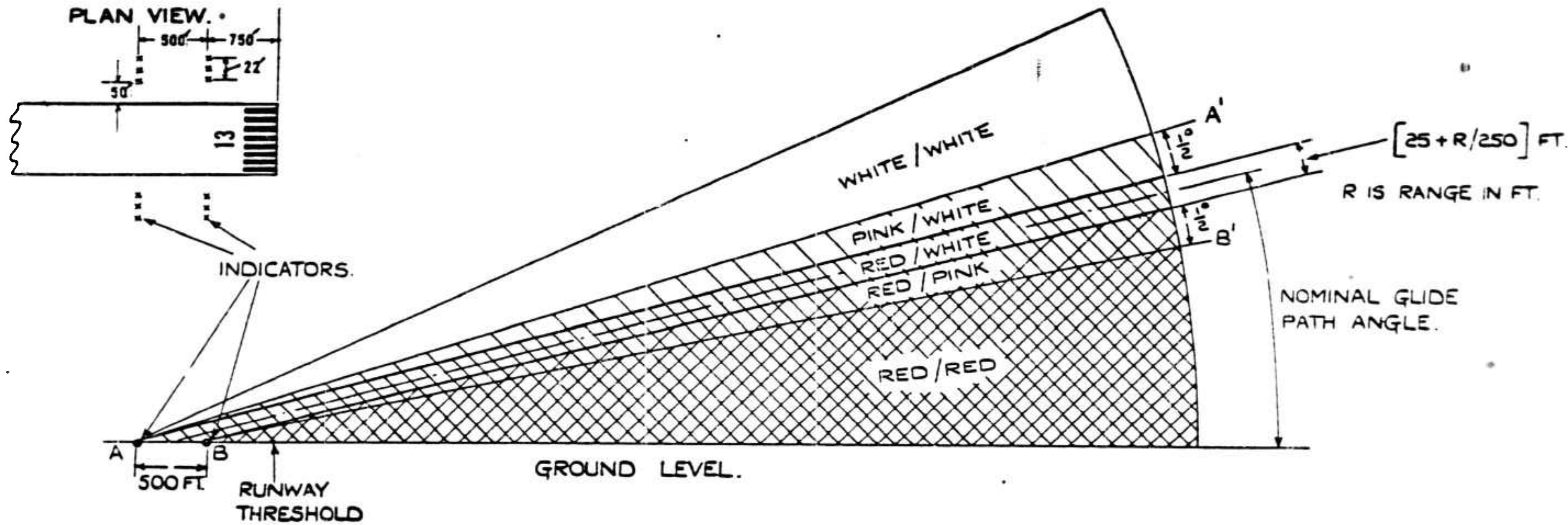


FIG. 11 COLOR INDICATION OF RAE SYSTEM

RED - WHITE SYSTEM

(R. A. E.)

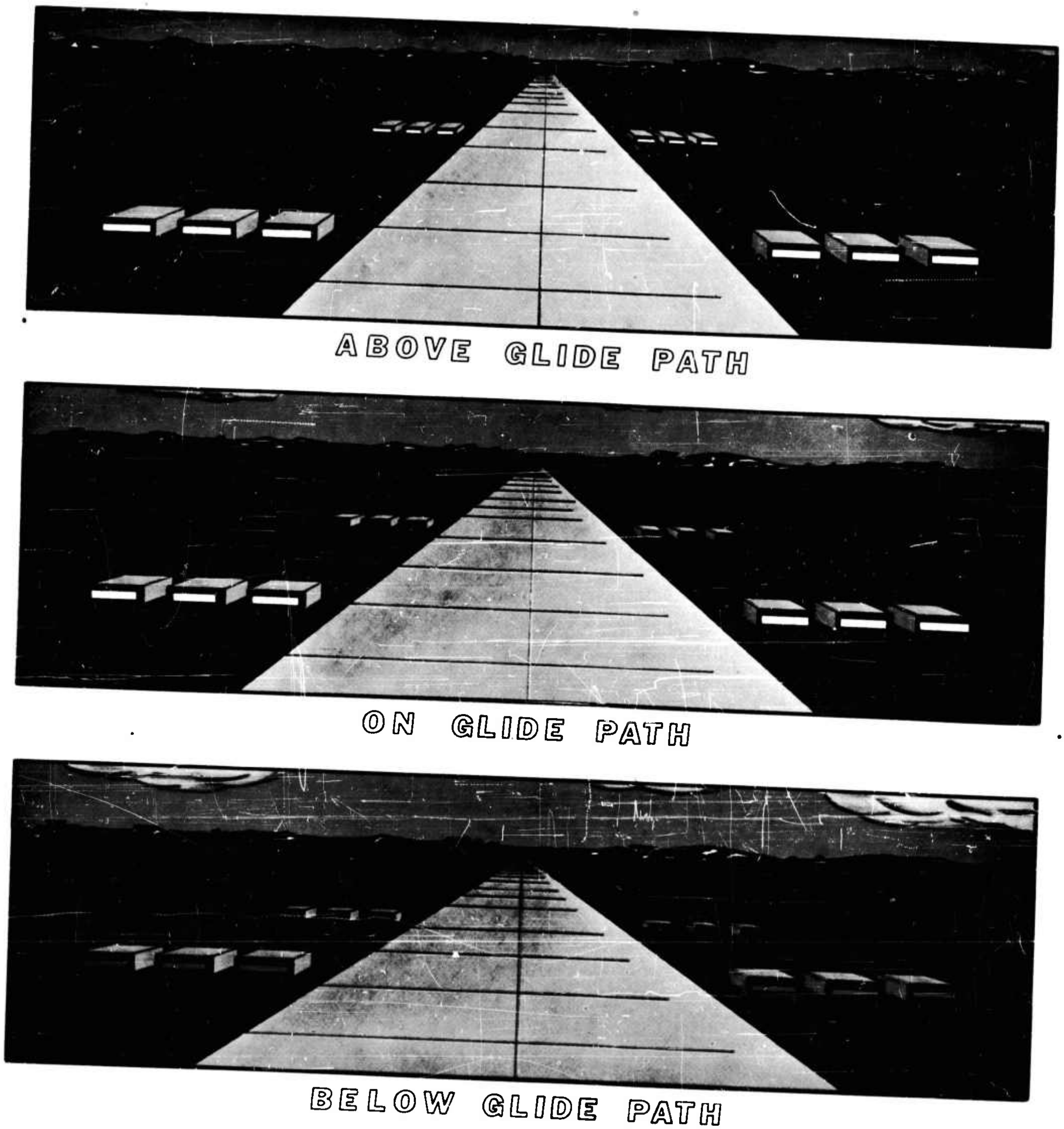


FIG. 12 COCKPIT VIEW OF RAE SYSTEM

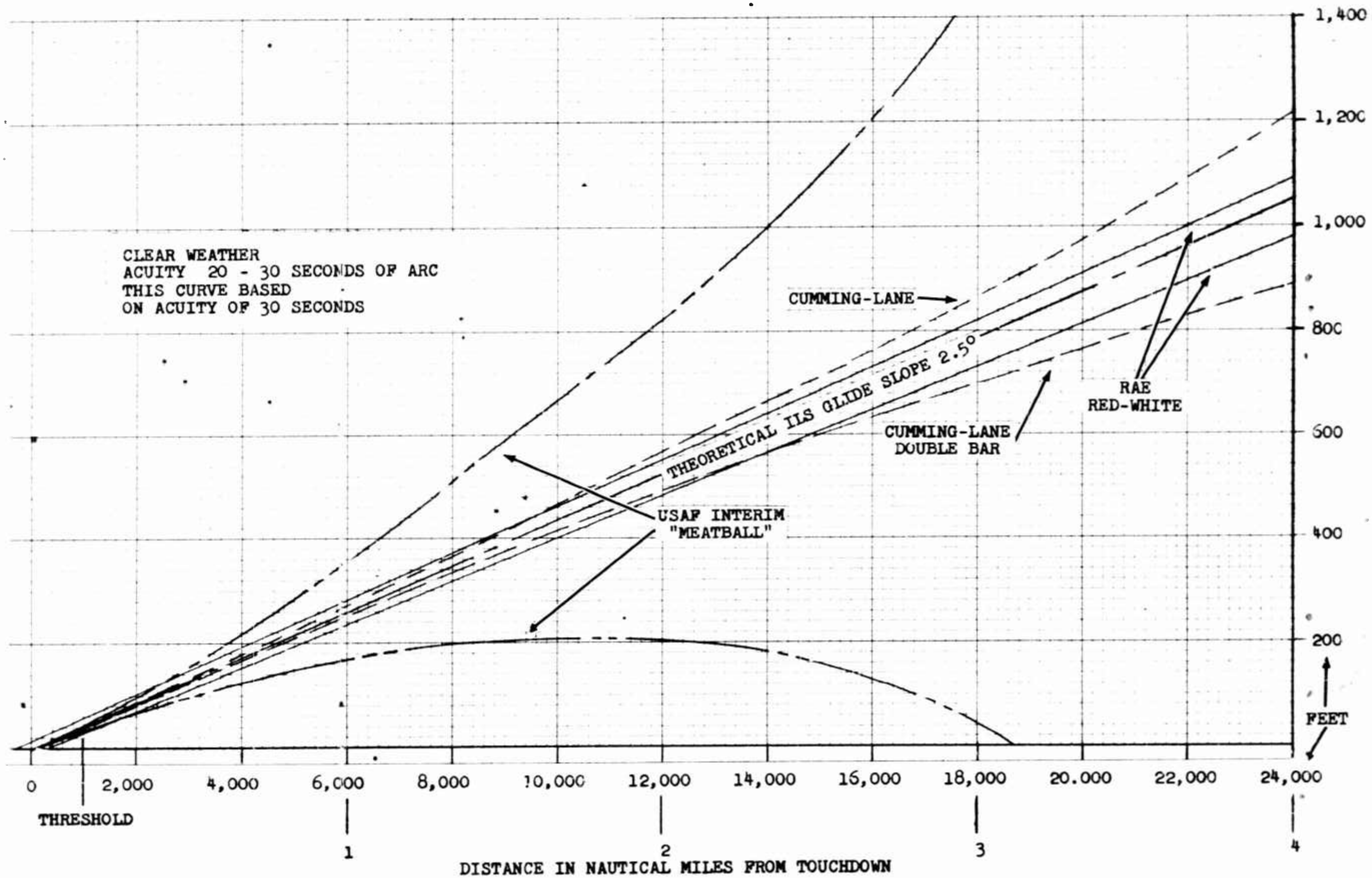


FIG. 13 COMPARATIVE SENSITIVITY OF THREE SYSTEMS

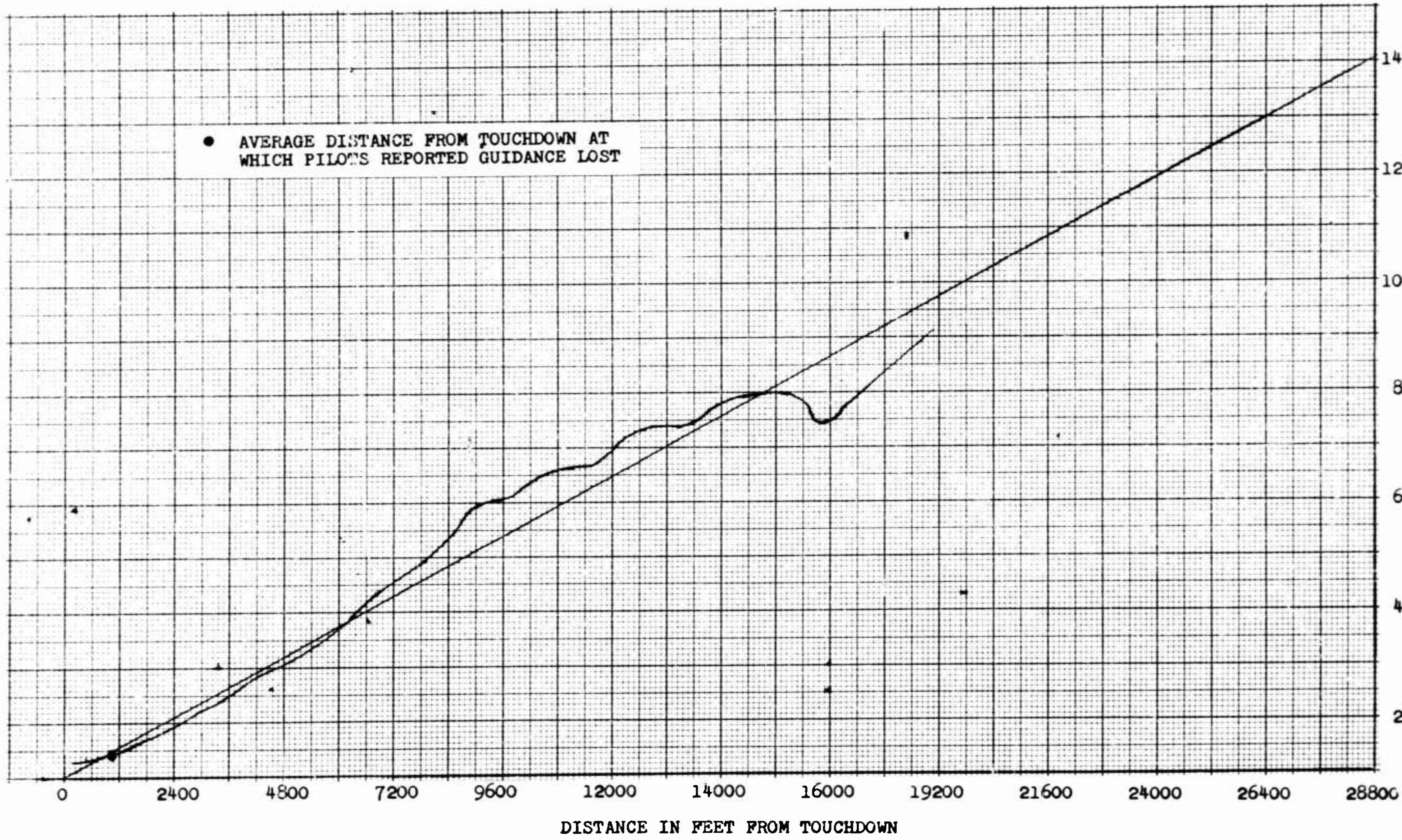


FIG. 14 PERFORMANCE PLOT DERIVED FROM THEODOLITE RECORDINGS AND IBM 709 COMPUTER, NAVY MIRROR SYSTEM

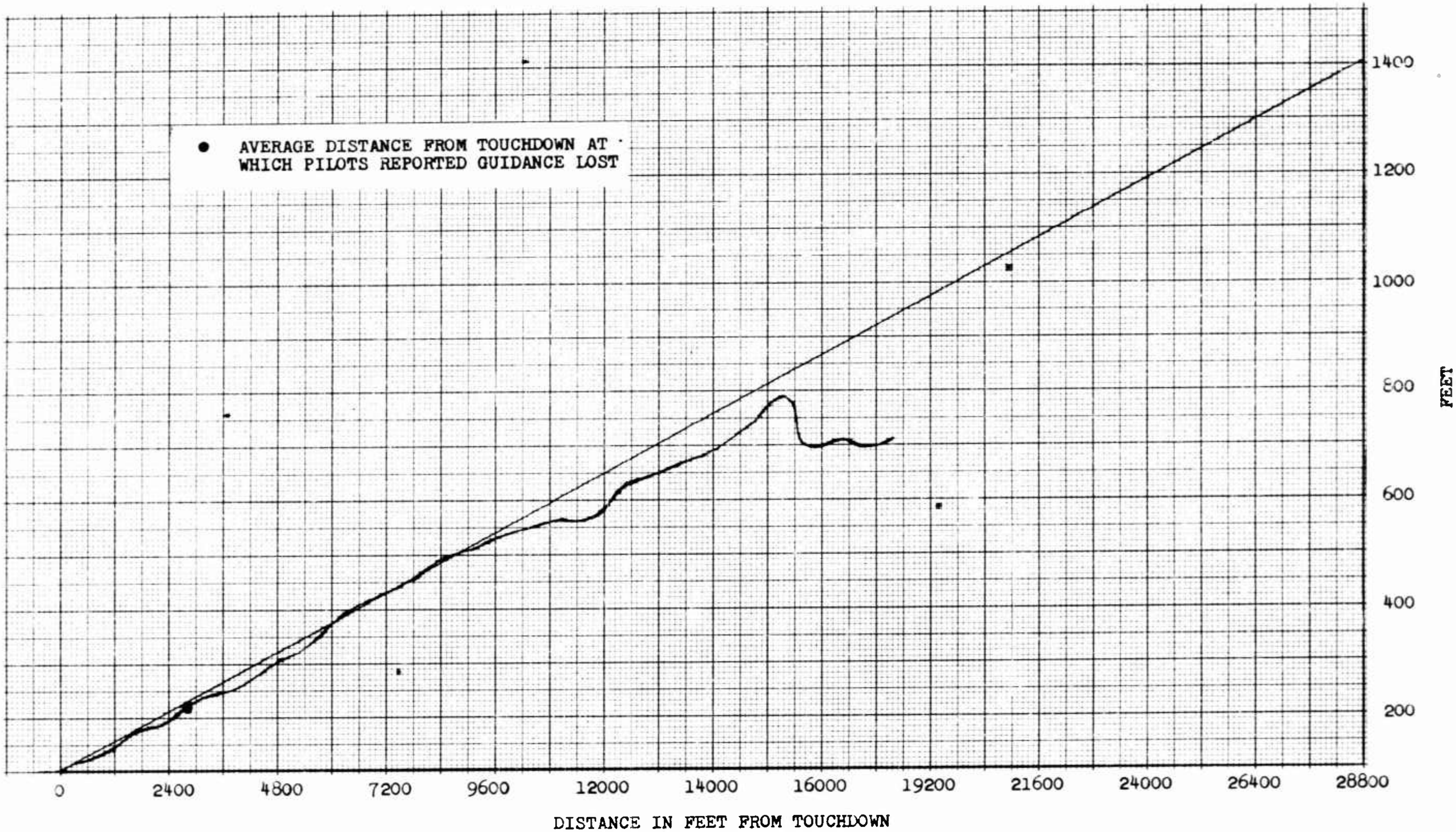


FIG. 15 PERFORMANCE PLOT DERIVED FROM THEODOLITE RECORDINGS AND IBM 709 COMPUTER, USAF INTERIM SYSTEM

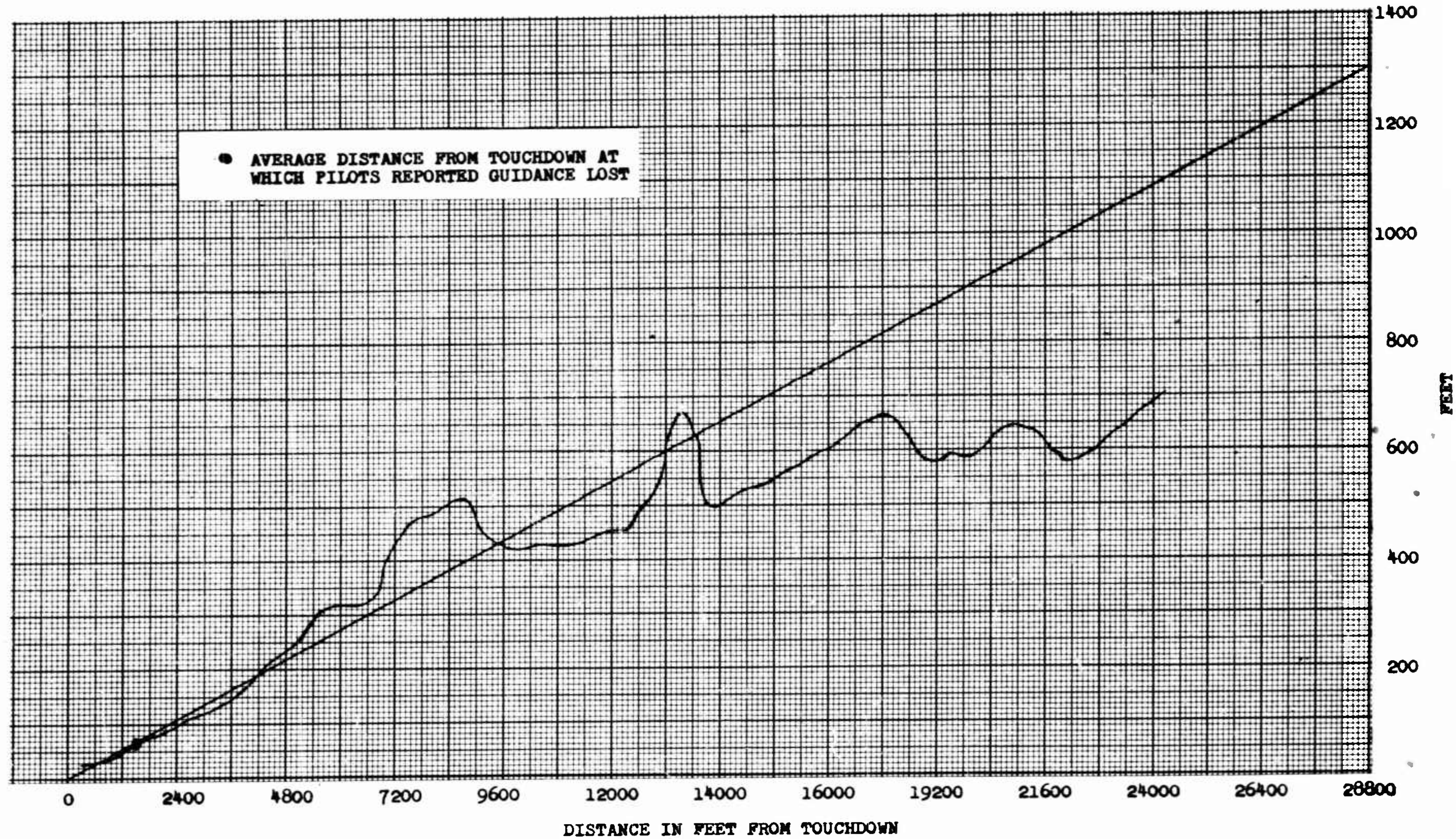


FIG. 16 PERFORMANCE PLOT DERIVED FROM THEODOLITE RECORDINGS AND IBM 709 COMPUTER, WESTINGHOUSE TRI-COLOR SYSTEM

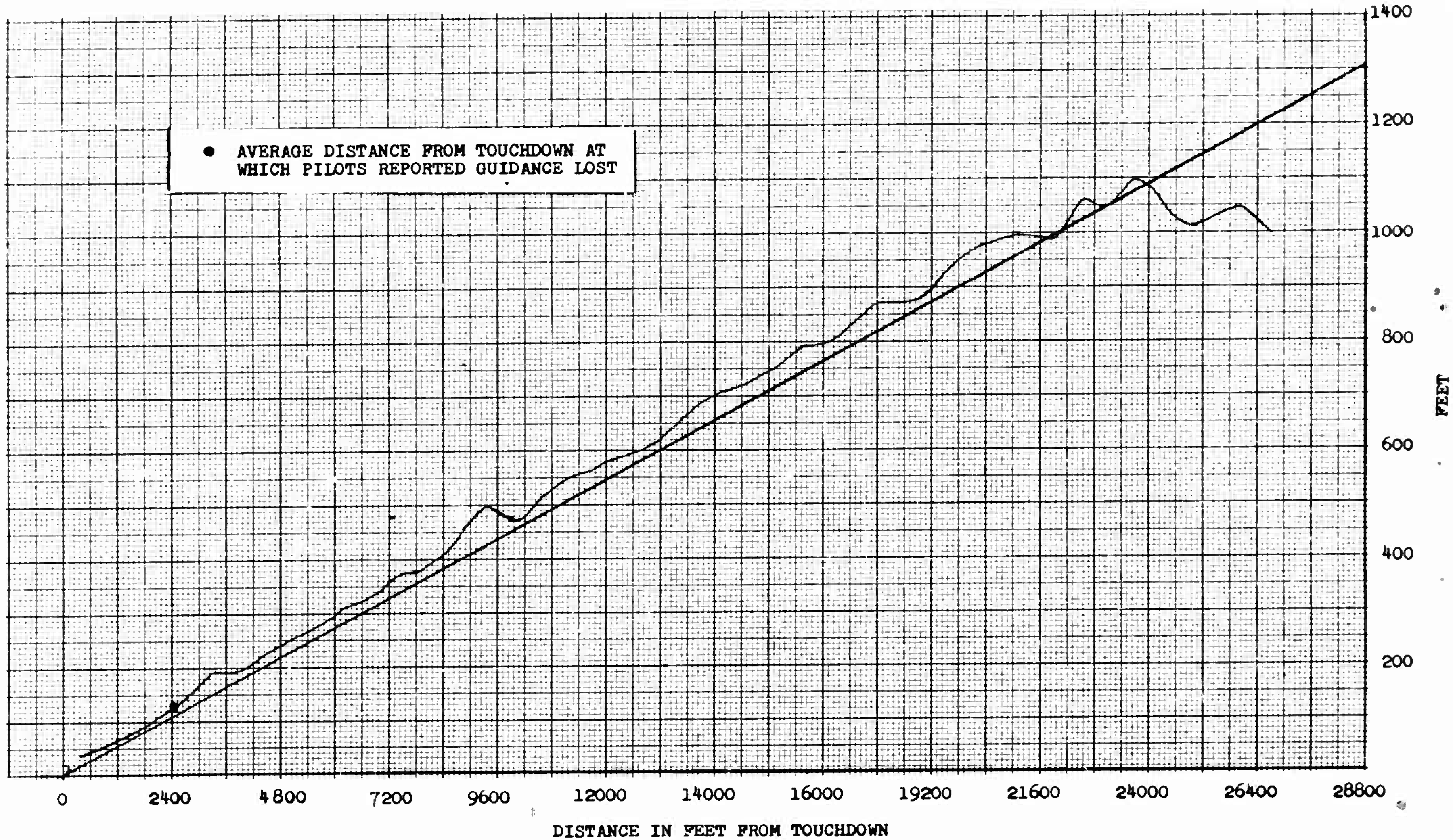


FIG. 17 PERFORMANCE PLOT DERIVED FROM THEODOLITE RECORDINGS AND IBM 709 COMPUTER, CUMMING-LANE SYSTEM

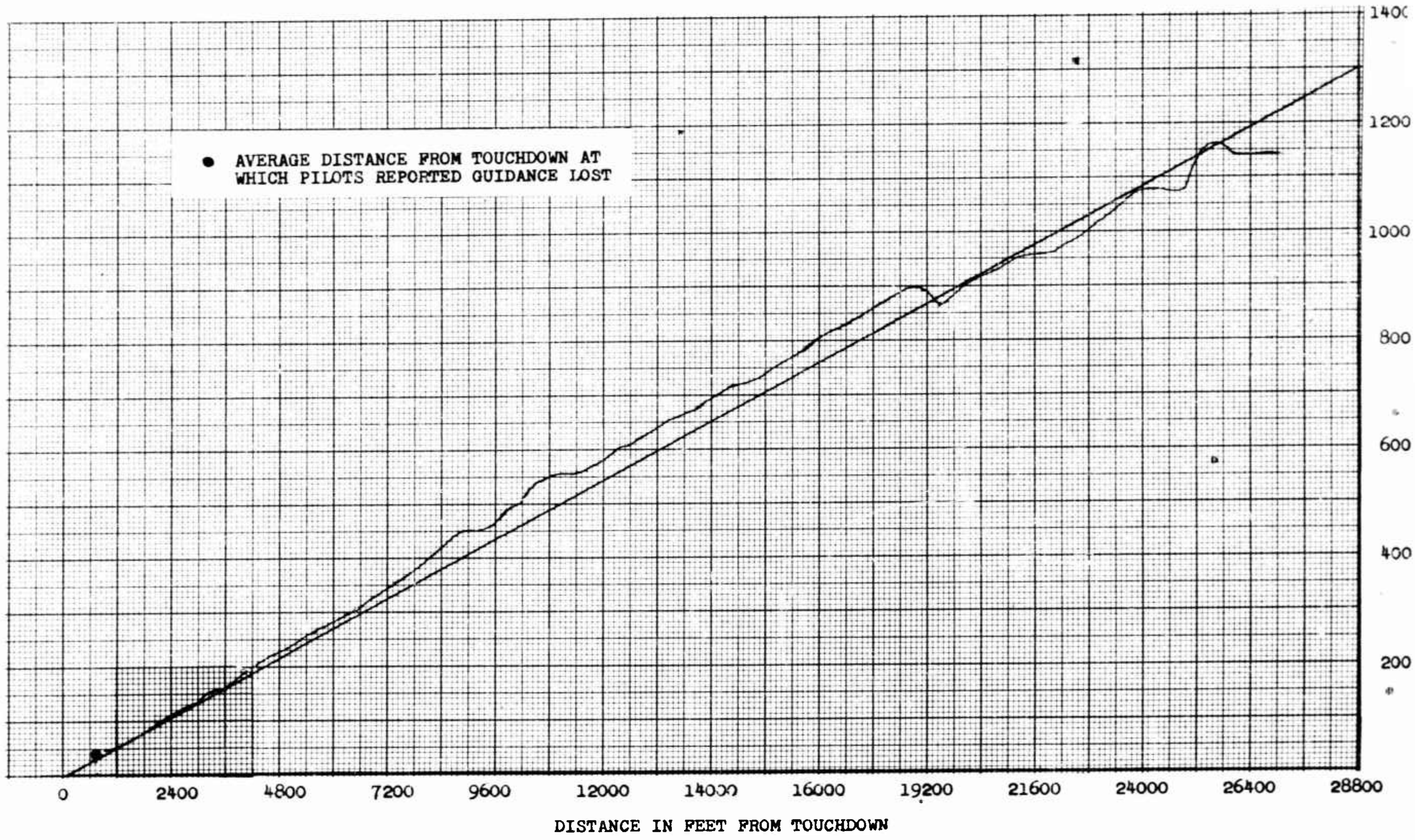


FIG. 18 PERFORMANCE PLOT DERIVED FROM THEODOLITE RECORDINGS AND IBM 709 COMPUTER, RAE SYSTEM

Electrical Data for Visual Glide Path Indicators

The electrical system common to four of the visual glide path systems is described below. Individual system details are included in paragraphs below.

Primary electrical service of 2400 volts, single phase, was connected to a 20-kw, 20-amp brightness control regulator which was connected to a four-system selector cabinet. A control panel in the lighthouse selected the system and light intensity step that was desired. Only one system could be operated at a time. Power was turned on by operation of a circuit breaker which controlled a remotely located oil switch. The system was protected with oil fused cutouts.

Double Bar: This system consisted of ten 300-watt PAR 56 and six 250-watt PAR 56 lamps. Each lamp was connected to a 300-watt, 20-amp/20-amp series isolation transformer. The 16 IL transformers were connected to the system selector cabinet with 1/c, #8, 5-kv direct burial cable.

Red-White: This system consisted of thirty-six 200-watt PAR 64 lamps. Each lamp was connected to a 200-watt, 20-amp/20-amp series isolation transformer. The 36 IL transformers were connected to the system selector cabinet with 1/c, #8, 5-kv direct burial cable.

Tri-Color: This system consisted of two 240-watt medium prefocus lamps, each one connected to a 300-watt, 20-amp/20-amp series isolation transformer. The IL transformers were connected to the system selector cabinet with 1/c, #8, 5-kv direct burial cable.

An alternative to a separate circuit for the Tri-Color system would be to use a series regulating transformer connected to the runway edge lights. This method could provide maximum intensity regardless of the runway light intensity. Changes to the flasher motor circuit would be required. This procedure would result in a reduction in installation cost.

U.S.A.F. Interim System: This system consisted of eighteen 200-watt PAR 56 lamps. Each lamp was connected to

a 200-watt, 6.6-amp/20-amp series isolation transformer. The 18 IL transformers were connected to the system selector cabinet with 1/c, #8, 5-kv direct burial cable.

Mirror: This system consisted of twenty 200-watt PAR 56 lamps. Electrical service and operation was locally controlled by use of a portable diesel electric plant.

Visual Glide Path Indicator	LAMP DATA								
	Type	Number Required	Watts	Amps. or Volts	Filter	Intensity - Candles		Beam Spread **	
						Maximum	Effect *	Horiz.	Vert.
Navy Mirror	PAR-56 PAR-56	12 8	399 100	115 V 6 V	Green Amber	30,000 240,000	6,000 112,800	30 9	10 5
Interim Mirror (USAF)	PAR-56 PAR-56	14 4	200 200	6.6 A 6.6 A	Green Amber	180,000 180,000	36,000 85,000	10 10	10 10
Westing-house	A19P	2	240	12.0V	Yellow Green Red	4,500	2,100 900 750	15 15 15	7 2 6
Cumming - Lane	PAR-56 PAR-56	10 6	300 250	20 A 12.5V	No Amber	28,000 75,000	28,000 35,000	50 35	20 10
RAE	PAR-64	36	200	20 A	Clear Red	130,000	130,000 22,000	15	6

* Effective intensity when used with filter.
** Total spread to 10 per cent of maximum intensity.

TABLE I CHARACTERISTICS OF LAMPS USED IN VISUAL GLIDE PATH INDICATORS

SAMPLE QUESTIONNAIRE SHOWING TABULATED RESPONSES

TO BE COMPLETED DURING PRE-FLIGHT BRIEFING

EVALUATION OF VISUAL GLIDE PATH INDICATORS

Pilot Background

Name ______________________________ Age ______________

Address ______________________________ Phone ______________

Employer ______________________________ Occupation ______________

Type of Flying you do

_______ Air Carrier   _______ Flight Test

_______ Commercial Operator   _______ Flight Instruction

_______ Executive or Business Flying   _______ Government (non-military)

_______ Private   _______ Military

Total flying time ______________ Instrument time ______________

Aircraft in which you have most experience ______________________

Aircraft flown in NAFEC test ______________________________

POST FLIGHT QUESTIONNAIRE

1. Do you consider that some type of visual approach aid is necessary, desirable, or unnecessary under the following conditions?

   a. Day, good visibility
   b. Night, good visibility, well-lit foreground
   c. Night, good visibility, unlit foreground
   d. Night, restricted visibility (but above minimum) with unlit foreground
   e. Day, reduced visibility (haze, smog, etc.)

CONDITION	RATINGS		
	Necessary	Desirable	Unnecessary
a. Day, clear,	2	24	34
b. Night, clear, well-lit	3	47	11
c. Night, clear, unlit	41	18	1
d. Night, reduced visibility	47	10	2
e. Day, reduced visibility	25	30	6

2. If you think that some type of visual approach aid is necessary or desirable, which airports should be given priority in installation of the aids?

   a. Airports with unfavorable terrain around them.
   b. Isolated airports with no surrounding lights.
   c. Main city terminal airports.
   d. Other, Marginal Runway length, etc.

Please check appropriate box

CATEGORY	ORDER OF PREFERENCE			
	1	2	3	4
a. Terrain limitation	47	8	3	3
b. Isolated	10	20	19	12
c. City terminal	5	13	13	27
d. Other, Marginal Runway Length, etc.	4	24	20	14

3. If you think that some type of visual approach aid is necessary or desirable, do you consider that any of the systems you flew at NAFEC wholly or partly fulfills the requirement?

Please check a box

AID	RATING		
	Wholly	Partly	Not at All
a. Double Bar	15	41	0
b. Tri-Color	1	3	15
c. Red-White	30	28	1
d. Mirror	0	7	12
e. Amber	0	7	14

4. Can you suggest any type of visual aid which you consider to be superior to any of the above systems? If so, describe.

The following questions concern your views in making comparisons among the systems. Check box on chart on page 4

5. On a circling approach, with a final approach shorter than a normal ILS pattern, altitude is reduced on base leg so as to be on glide path after turning on final. Did you find that one aid was more helpful than any other, that two or more were equally helpful, or that none of the aids gave any guidance until lined up on final?

6. Did any system give more assistance than the others in lining up on the runway center line and maintaining alignment, were two or more equally helpful, or were all ineffective in providing lateral guidance?

7. At long range (over 3 miles) do you consider sensitivity of any aid to be preferable, are two or more equally good, or are none satisfactory?

8. At short range (less than 1 mile) do you consider sensitivity of any aid to be preferable, are two or more equally good, or are none satisfactory?

9. It is desirable during an approach to know your rate of divergence from, and approach to, the proper glide path. Did you find that one system was superior in providing this rate information, that two or more were equally effective, or that none was effective?

10. At some point on the glide path, you were ready to transfer your attention from the visual approach aid to concentrate on a flare-out and landing. In regard to continuity of guidance to this point, was one system better, two or more equally helpful, or were none satisfactory?

11. During the flare-out and landing phase, did one system provide more aid, were two or more equally effective, or were none of any assistance?

12. It is possible that an approach aid might divert your attention or disturb your judgment during landing. Do you consider one aid to be preferable in this respect, two or more to be equally satisfactory, or none to be satisfactory.

13. There is a possibility of confusion with other lights on or around an airport. In this respect, do you consider one aid to be preferable to the others, two or more to be equally distinctive, or none to be satisfactory?

14. Each system involves in some way the use of colored lights. Do you favor the choice of colors in one system over the others, approve equally of all, or consider none to be satisfactory?

15. It is generally accepted that an instinctive response to a change in signal from any flight aid is better than a response delayed by mental interpretation. Do you think that one aid can more easily be flown instinctively, that two or more are equal in this respect, or that none could be flown instinctively?

16. In cases where the aircraft breaks from cloud in near-minimum conditions, the rapidity with which flight path corrections can be made depends upon the speed of interpretation of the approach aid indications. Do you think that one aid would be superior under these conditions, that two or more would be equally good, or that none would be satisfactory?

17. <u>THIS QUESTION TO BE ANSWERED ONLY BY PILOTS WHO HAVE EXPERIENCED POOR VISIBILITY CONDITIONS ON THE APPROACH.</u>

Consider the guidance received and freedom from distortion in haze or precipitation. Is one aid better than the others under these conditions, are two or more equally satisfactory, or are none satisfactory?

18. Components of many airport aids constitute some degree of obstruction in the event of an aircraft running off the runway, but it is desirable that the obstruction potential should not be such as to cause concern to the pilot. Do you consider one aid to be preferable in this respect, two or more to be equally satisfactory, or none to be satisfactory?

19. If you feel that for a particular aspect you are equally satisfied with two or more systems, please make a check mark in the column for the aids concerned.

ASPECTS (Question Number)	SATISFACTION EXPRESSED WITH:								
	Double Bar		Tri-Color	Red - White		Mirror	Amber	None	
	A	B	A	A	B	A	A	A	B
5 Help on Base Leg	10	17	2	10	14	1	1	2	10
6 Alignment in azimuth	6	18	1	8	5	0	0	7	13
7 Sensitivity, long range	9	25	0	16	24	0	2	0	2
8 Sensitivity, short range	4	23	2	14	35	7	3	0	0
9 Rate information	9	26	1	13	27	5	0	1	2
10 Continuity of guidance	4	18	2	14	32	6	2	2	1
11 Flare, landing	0	5	1	7	10	6	2	9	25
12 Effect on judgment	4	16	0	13	20	3	1	1	9
13 Confusion with other lights	7	19	3	13	18	4	5	1	8
14 Color of lights	3	9	2	12	29	4	5	1	4
15 Instinctive response	6	24	1	14	20	2	1	0	4
16 Rapidity of correction	6	23	1	14	22	2	1	1	3
17 Distortion (haze, precipitation)*	1	2	0	3	0	3	1	1	0
18 Obstruction Potential	2	15	4	10	27	1	1	1	3

20. Do you consider that any system has any inherent dangers? If so, please describe?

*Answered only by pilots who experienced such weather phenomena.

NOTE (Not a part of questionnaire): In the tabulation above, column "A" represents responses from 19 pilots who flew all five systems. Column "B" represents responses from an additional 43 pilots who flew only RAE and Cumming-Lane systems. Majority of 707/KC-135 pilots are included in the latter group.

21. Do you find that, using these approach aids, you require less reference to normal aircraft instruments during an approach, the same amount of reference, or more reference? Check a box.

AID	AMOUNT OF REFERENCE		
	Less	Same	More
a. Double Bar	25	27	5
b. Tri-Color	3	8	2
c. Red-White	26	32	3
d. Mirror	4	8	3
e. Amber	3	8	3

22. In the final stages of the approach (last half mile) did you feel that these aids were bringing you in too high, about right, or too low? Check a box.

AID	INSTINCTIVE FEELING		
	Too High	About Right	Too Low
a. Double Bar	9	39	4
b. Tri-Color	0	4	2
c. Red-White	6	49	1
d. Mirror	1	7	3
e. Amber	3	6	3

23. The systems are all adjusted to provide a glide slope of approximately 2.5°. Considering the type airplane you flew, is this angle:

Too Flat 9
About Right 46
Too Steep 1

24. The systems are all installed to provide a glide angle intersection with the runway 1,000 feet from threshold. Considering the type of aircraft you flew, is this location

Too Far 23
About Right 39
Too Close to Threshold 0

NOTE: With regard to questions 23 and 24, the reader should bear in mind that glide angle and point of touchdown can be varied for different conditions of terrain, obstructions, and runway lengths. In the case of Atlantic City, 2.5° and 1,000 feet were selected.

25. Taking all factors into consideration, which of the five systems of visual approach guidance do you prefer?
Red-White 36 Double-Bar 22

The following questions concern the test procedure.

26. Were the briefings on the visual approach aids satisfactory? If not, what changes or additions would you suggest?

27. Do you feel that any of the aids could have been improved by adjustment of the brightness of any of the lights?

28. Compared with your own standard of approach and landing, do you consider your approaches on each aid to be good, average, or bad? If below average, would you care to state what you attribute this to? Use the space provided under "General Comments" below.

AID	QUALITY OF APPROACH		
	Good	Average	Bad
a. Double Bar	27	32	2
b. Tri-Color	1	3	5
c. Red-White	38	25	3
d. Mirror	3	10	3
e. Amber	0	8	7

General Comments - This space is provided for you to make any further comments on any phase of the test not covered previously, or to expand on any of your answers above.

Measurement of Time Required to Locate Glide Path

Consonant with the work details, as outlined in Task Assignment No. D-2-8045, the following data regarding the ease of locating the glide slope and a measure of the time required to reach proper alignment, is provided herein.

The highly qualified subject pilots participating in this phase, aside from previous experience with the visual glide path systems, possessed dissimilar backgrounds. The aircraft employed were likewise chosen to afford wide sampling in addition to their previous use during the evaluation.

Procedure

The evaluation was conducted by placing the subject pilot at varying altitudes above or below the desired path at a fixed distance (3 nautical miles) and at a designated mark the pilot adjusted his position in space to coincide with the optimum on-course path.

FLIGHT DATA RESULTS, PILOT A

Flying an Aero Commander, distance 3 miles:

Approach	System	Altitude	Time
1	Red/White	1,000	8 seconds
2	Double Bar	1,000	7 seconds
3	Red/White	600	20 seconds
4	Double Bar	600	18 seconds
5	Red/White	1,000	10 seconds
6	Double Bar	1,000	8 seconds
7	Red/White	600	18 seconds
8	Double Bar	600	20 seconds
9	Red/White	1,000	6 seconds
10	Double Bar	1,000	4 seconds
11	Red/White	600	17 seconds
12	Double Bar	600	18 seconds

Flight conditions were VFR with a calm wind.

FLIGHT DATA RESULTS, PILOT B

Flying a C-131 (Convair 340), distance 3 miles:

Approach	System	Altitude	Time
13	Red/White	1,300	15 seconds
14	Double Bar	1,300	14 seconds
15	Red/White	700	12 seconds
16	Double Bar	700	15 seconds
17	Red/White	1,300	12 seconds
18	Double Bar	1,300	15 seconds
19	Red/White	700	17 seconds
20	Double Bar	700	17 seconds
21	Red/White	1,300	16 seconds
22	Double Bar	1,300	12 seconds
23	Red/White	700	14 seconds
24	Double Bar	700	15 seconds

Flight conditions were VFR with a calm wind.

Results of Checking RAE System with a Sextant

After a series of strong windstorms and some settling of the concrete bases of the RAE units, the entire system was rechecked for adjustment using a standard USAF navigator bubble sextant, Model AN 5854-1. These sightings were made by Maj. D. F. Edwards, NAFEC, an Air Force Navigator, in the company of the task manager and Mr. J. C. Morrall of the RAE. The entire series of sightings on all 12 units required only about 30 minutes to perform. As shown in the following results, some maladjustments developed, but were easily and quickly determined and corrected. The desired angles were: upwind bars, 2° 48 minutes; downwind bars, 2° 12 minutes. It should be noted here that the system remained completely usable even with the settings below.

X	X	X	X	X	X
2° 46'	2° 48'	2° 54'	3° 01'	2° 52'	2° 50'
2° 44'	2° 49'	2° 56'	3° 01'	2° 54'	2° 45'
2° 47'	2° 49'	2° 52'	3° 00'	2° 53'	2° 46'
2° 46'	2° 49'	2° 52'	3° 00'	2° 51'	2° 48'
2° 45'	2° 52'	2° 55'	3° 02'		2° 50'
2° 48'	2° 52'	2° 55'			
2° 45'	2° 50'	2° 55'			
2° 47'	2° 50'				
Average	Average	Average	Average	Average	Average
2° 46'	2° 50'	2° 54'	3° 01'	2° 53'	2° 48'

1 3

X	X	X	X	X	X
2° 07'	2° 14'	2° 18'	2° 17'	2° 09'	2° 08'
2° 06'	2° 10'	2° 19'	2° 22'	2° 10'	2° 09'
2° 08'	2° 16'	2° 19'	2° 22'	2° 07'	2° 10'
2° 06'	2° 14'	2° 21'	2° 19'	2° 12'	2° 07'
2° 06'	2° 12'	2° 21'	2° 20'	2° 10'	2° 09'
2° 07'	2° 14'	2° 20'	2° 20'	2° 12'	2° 07'
2° 07'	2° 15'	2° 20'		2° 10'	
Average	Average	Average	Average	Average	Average
2° 07'	2° 14'	2° 20'	2° 20'	2° 10'	2° 08'

The click stops incorporated in the adjusting screw (1 minute of arc per click) made it very easy to get all the units adjusted to the proper angle. Flight checking confirmed that the units all were properly adjusted.

These computer data sheets are from which points used in plotting Figs. 14 through 18 were taken. In addition to the mean glide paths shown on the plots, these sheets contain data which report the distance, from touchdown, at which the lights could be seen, the distance at which guidance was obtained, and the distance at which guidance was lost.

In this appendix, the group of sheets for each system is considered as a series. Each system is identified by a letter, and each sheet within a series is numbered. Thus, the first computer data sheet for the Navy Mirror System is identified as Sheet A-1. Other letter designators are:

USAF Interim - B
Westinghouse Tri-Color - C
Cumming-Lane - D
RAE - E

Points referred to above are shown on the sheets (starting on sheet No. 2 of each series) as Mark 1, Mark 2, and Mark 3, respectively. Distances shown for each system on sheet No. 2 of each series are Mark 1 to touchdown, Mark 2 to touchdown, Mark 3 to touchdown, Mark 1 to Mark 2, Mark 2 to Mark 3, and Mark 1 to Mark 3.

The bands referred to are 600-foot strips beginning with the section over touchdown as band 1, and increasing in 600-foot increments to 5 miles from touchdown. Everything recorded in band 46 is beyond 5 miles. All distances and deviations are expressed in feet.

Deviations in the lateral plane, although recorded, have not been considered in this test, because pilots were briefed that the systems were designed principally to provide guidance in the vertical plane.

In the symbol key, on sheet No 1 of each series, the bands should be defined as approach path sections, rather than runway sections, since all bands except No.1 and part of No. 2 lie outside the actual runway limits.

SYMBOL KEY

D(MJ - T) - DISTANCE (FEET) BETWEEN MARK J AND TOUCHDOWN POINT

D(MJ - MK) - DISTANCE (FEET) BETWEEN MARK J AND MARK K

BAND 1 - RUNWAY SECTION BELOW THE TOUCHDOWN POINT

BAND J - RUNWAY SECTION BETWEEN T + (J-2)X600 AND T + (J-1)X600 FEET (J GREATER THAN 1, LESS THAN 46)

BAND 46 - RUNWAY SECTION BEYOND T + 5 MILES

N - NUMBER OF POINTS CONTRIBUTING TO THE BAND AVERAGE

V-MN - MEAN OF THE DEVIATIONS IN THE VERTICAL PLANE

H-MN - MEAN OF THE DEVIATIONS IN THE LATERAL PLANE

SD-V - STANDARD DEVIATION ABOUT V-MN IN THE VERTICAL PLANE

SD-H - STANDARD DEVIATION ABOUT H-MN IN THE LATERAL PLANE

V-MAX - MAXIMUM VERTICAL DEVIATION

H-MAX - MAXIMUM LATERAL DEVIATION

* - STARRED QUANTITY REPRESENTS AN AVERAGE FOR THE ENTIRE SET OF BANDS (EXCEPTING BAND 1)

COMPUTER DATA SHEET A - 1
VISUAL GLIDE PATH INDICATOR
NAVY MIRROR SYSTEM

RUN	D(M1 - T)	D(M2 - T)	D(M3 - T)	D(M1 - M2)	D(M2 - M3)	D(M1 - M3)
1	16103.294	6242.604	365.846	9861.388	5877.335	15738.088
2	22735.524	5296.961	936.282	17438.685	4360.681	21799.273
3	24374.753	6076.483	727.605	18298.700	5349.119	23647.574
4	19295.197	6427.145	296.566	12869.395	6132.898	19000.554
5	22870.803	18749.763	963.090	4127.582	17786.673	21907.773
6	20576.078	16193.824	4023.583	4382.829	12170.259	16552.595
7	18762.978	7993.387	210.620	10769.889	7782.817	18552.405

	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6	BAND 7	BAND 8
N	1	5	7	7	7	7	6	8
V-MN	5164.782	17.626	0.595	-5.341	-10.060	-10.030	-12.267	-4.814
SD-V	0.	11.837	6.450	8.030	11.398	12.961	12.323	17.483
V-MAX	5164.782	29.988	11.335	18.796	30.533	30.774	31.414	38.031
H-MN	-2.117	7.774	1.798	6.552	5.604	3.438	0.754	13.080
SD-H	0.	5.788	10.794	3.757	4.785	2.784	6.973	31.802
H-MAX	2.117	15.608	22.187	11.309	13.311	8.389	11.740	89.111

	BAND 9	BAND 10	BAND 11	BAND 12	BAND 13	BAND 14	BAND 15	BAND 16
N	8	7	7	7	4	3	3	2
V-MN	-9.123	-5.887	-1.673	6.440	16.941	36.769	41.157	75.668
SD-V	22.997	34.014	36.936	45.214	37.481	37.363	41.998	31.783
V-MAX	36.121	50.077	68.262	77.813	58.725	71.392	95.118	107.451
H-MN	11.412	15.876	14.438	19.556	6.197	15.004	17.778	36.924
SD-H	13.258	13.616	16.983	16.312	22.159	26.983	30.313	20.015
H-MAX	23.605	30.582	39.520	45.073	40.333	47.972	55.654	56.939

	BAND 17	BAND 18	BAND 19	BAND 20	BAND 21	BAND 22	BAND 23	BAND 24
N	3	2	3	2	3	2	2	3
V-MN	86.772	67.261	74.860	67.311	47.415	60.103	48.147	21.654
SD-V	23.135	0.717	26.903	45.504	54.747	60.736	57.129	43.191
V-MAX	112.127	67.978	98.853	112.815	124.733	120.839	105.275	82.731
H-MN	33.965	27.727	44.480	43.000	44.209	52.729	54.524	57.010
SD-H	13.833	3.373	8.861	5.486	7.117	5.112	2.547	0.511
H-MAX	53.196	31.100	51.280	48.485	54.234	57.841	57.071	57.380

COMPUTER DATA SHEET A - 3
VISUAL GLIDE PATH INDICATOR
NAVY MIRROR SYSTEM

	BAND 25	BAND 26	BAND 27	BAND 28	BAND 29	BAND 30	BAND 31	BAND 32
N	2	2	2	2	1	1	1	1
V-MN	25.284	18.079	3.278	-18.223	-102.525	-105.749	-93.890	-81.425
SD-V	41.913	38.055	52.958	61.725	0.	0.	0.	0.
V-MAX	67.197	56.134	56.237	79.948	102.525	105.749	93.890	81.425
H-MN	62.036	71.776	93.342	125.340	164.712	202.717	233.019	243.195
SD-H	0.100	0.866	0.003	2.036	0.	0.	0.	0.
H-MAX	62.136	72.643	93.346	127.376	164.712	202.717	233.019	243.195

	BAND 33	BAND 34	BAND 35	BAND 36	BAND 37	BAND 38	BAND 39	BAND 40
N	1	0	0	0	0	0	0	0
V-MN	-67.941	0.	0.	0.	0.	0.	0.	0.
SD-V	0.	0.	0.	0.	0.	0.	0.	0.
V-MAX	67.941	0.	0.	0.	0.	0.	0.	0.
H-MN	242.717	0.	0.	0.	0.	0.	0.	0.
SD-H	0.	0.	0.	0.	0.	0.	0.	0.
H-MAX	242.717	0.	0.	0.	0.	0.	0.	0.

	BAND 41	BAND 42	BAND 43	BAND 44	BAND 45	BAND 46
N	0	0	0	0	0	0
V-MN	0.	0.	0.	0.	0.	0.
SD-V	0.	0.	0.	0.	0.	0.
V-MAX	0.	0.	0.	0.	0.	0.
H-MN	0.	0.	0.	0.	0.	0.
SD-H	0.	0.	0.	0.	0.	0.
H-MAX	0.	0.	0.	0.	0.	0.

PERFORMANCE OF THE SYSTEM

*V-MN	5.827
*SD-V	27.357
*V-MAX	71.632
*H-MN	61.646
*SD-H	8.630
*H-MAX	73.868
*D(M3 - T)	1074.799

7 RUNS HAVE BEEN PROCESSED. THERE IS NO MORE DATA IN THE SET.

COMPUTER DATA SHEET A - 5
VISUAL GLIDE PATH INDICATOR
NAVY MIRROR SYSTEM

SYMBOL KEY

D(MJ - T)	- DISTANCE (FEET) BETWEEN MARK J AND TOUCHDOWN POINT
D(MJ - MK)	- DISTANCE (FEET) BETWEEN MARK J AND MARK K
BAND 1	- RUNWAY SECTION BELOW THE TOUCHDOWN POINT
BAND J	- RUNWAY SECTION BETWEEN T + (J-2)X600 AND T + (J-1)X600 FEET (J GREATER THAN 1, LESS THAN 46)
BAND 46	- RUNWAY SECTION BEYOND T + 5 MILES
N	- NUMBER OF POINTS CONTRIBUTING TO THE BAND AVERAGE
V-MN	- MEAN OF THE DEVIATIONS IN THE VERTICAL PLANE
H-MN	- MEAN OF THE DEVIATIONS IN THE LATERAL PLANE
SD-V	- STANDARD DEVIATION ABOUT V-MN IN THE VERTICAL PLANE
SD-H	- STANDARD DEVIATION ABOUT H-MN IN THE LATERAL PLANE
V-MAX	- MAXIMUM VERTICAL DEVIATION
H-MAX	- MAXIMUM LATERAL DEVIATION
*	- STARRED QUANTITY REPRESENTS AN AVERAGE FOR THE ENTIRE SET OF BANDS (EXCEPTING BAND 1)

COMPUTER DATA SHEET B - 1
VISUAL GLIDE PATH INDICATOR
USAF INTERIM SYSTEM

RUN	D(M1 - T)	D(M2 - T)	D(M3 - T)	D(M1 - M2)	D(M2 - M3)	D(M1 - M3)
1	23783.680	16192.759	8054.536	7595.241	8139.655	15733.300
2	24857.092	11778.740	11192.068	13079.146	593.263	13667.660
3	4666.839	9056.352	1268.755	13492.562	7787.864	5856.174
4	17296.086	15138.538	296.675	2157.828	14842.099	16999.649
5	25957.114	17268.107	919.582	8690.307	16348.526	25037.552
6	10864.032	8453.214	555.150	2919.274	7902.368	10333.602
7	20557.047	18044.442	442.147	2512.712	17602.453	20115.049
8	26072.655	14080.151	1164.021	11994.893	12916.312	24908.653
9	22321.402	15047.253	1271.601	7283.697	13775.945	21050.637

COMPUTER DATA SHEET B - 2
VISUAL GLIDE PATH INDICATOR
USAF INTERIM SYSTEM

	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6	BAND 7	BAND 8
N	2	4	6	9	7	7	10	8
V-MN	2597.119	3.184	-5.382	-2.479	-14.029	-9.020	-7.762	-21.458
SD-V	2579.999	4.330	3.857	10.710	9.261	24.220	29.228	36.167
V-MAX	5177.119	9.839	10.600	22.434	32.041	44.952	49.607	63.269
H-MN	5.150	-5.249	-1.260	6.028	-7.112	-3.128	-0.418	-2.242
SD-H	6.276	4.573	7.559	24.732	10.528	15.228	16.633	11.313
H-MAX	11.427	12.307	11.305	68.266	17.102	23.832	28.656	18.038

	BAND 9	BAND 10	BAND 11	BAND 12	BAND 13	BAND 14	BAND 15	BAND 16
N	9	7	6	11	8	12	7	10
V-MN	-15.929	-17.568	-6.532	7.833	11.037	5.321	13.775	3.798
SD-V	34.699	42.320	48.649	55.066	78.038	95.094	99.573	89.825
V-MAX	75.090	90.224	105.639	120.204	134.923	162.981	175.311	183.644
H-MN	-15.580	-1.881	-36.723	-27.600	-51.244	-57.180	-143.403	8.680
SD-H	14.425	39.839	40.610	77.757	152.083	202.006	381.523	26.846
H-MAX	39.655	91.238	117.058	249.394	442.414	721.872	1075.866	61.710

	BAND 17	BAND 18	BAND 19	BAND 20	BAND 21	BAND 22	BAND 23	BAND 24
N	9	6	8	7	9	9	6	7
V-MN	-6.680	-15.226	-25.589	-41.664	-73.071	-38.529	-49.713	-54.682
SD-V	88.610	86.409	75.097	80.967	98.832	70.168	83.822	75.207
V-MAX	192.543	204.039	218.170	227.691	231.170	228.838	227.204	221.369
H-MN	8.828	0.564	2.033	5.900	5.451	1.290	9.406	5.847
SD-H	37.293	44.724	34.537	35.440	33.770	37.615	39.868	42.098
H-MAX	68.896	72.429	70.515	69.113	73.702	80.237	85.724	88.062

	BAND 25	BAND 26	BAND 27	BAND 28	BAND 29	BAND 30	BAND 31	BAND 32
N	8	5.	6	4	3	4	1	1
V-MN	-65.127	-62.908	-59.372	-31.511	-163.318	-156.651	-217.735	-226.029
SD-V	72.592	56.064	76.235	75.553	39.430	48.409	0.	0.
V-MAX	222.472	127.648	147.358	107.177	193.922	207.425	217.735	226.029
H-MN	14.512	6.771	11.727	32.068	12.370	12.239	67.330	61.503
SD-H	39.870	55.970	50.425	57.861	23.059	34.399	0.	0.
H-MAX	100.737	117.745	119.296	100.059	30.391	54.157	67.330	61.503

	BAND 33	BAND 34	BAND 35	BAND 36	BAND 37	BAND 38	BAND 39	BAND 40
N	0	0	0	0	0	0	0	0
V-MN	0.	0.	0.	0.	0.	0.	0.	0.
SD-V	0.	0.	0.	0.	0.	0.	0.	0.
V-MAX	0.	0.	0.	0.	0.	0.	0.	0.
H-MN	0.	0.	0.	0.	0.	0.	0.	0.
SD-H	0.	0.	0.	0.	0.	0.	0.	0.
H-MAX	0.	0.	0.	0.	0.	0.	0.	0.

	BAND 41	BAND 42	BAND 43	BAND 44	BAND 45	BAND 46
N	0	0	0	0	0	0
V-MN	0.	0.	0.	0.	0.	0.
SD-V	0.	0.	0.	0.	0.	0.
V-MAX	0.	0.	0.	0.	0.	0.
H-MN	0.	0.	0.	0.	0.	0.
SD-H	0.	0.	0.	0.	0.	0.
H-MAX	0.	0.	0.	0.	0.	0.

COMPUTER DATA SHEET 3 - 4
VISUAL GLIDE PATH INDICATOR
USAF INTERIM SYSTEM

PERFORMANCE OF THE SYSTEM

*V-MN	-43.323
*SD-V	54.465
*V-MAX	144.566
*H-MN	-2.596
*SD-H	51.374
*H-MAX	136.729
*D(M3 - T)	2796.059

9 RUNS HAVE BEEN PROCESSED. THERE IS NO MORE DATA IN THE SET.

COMPUTER DATA SHEET B - 5
VISUAL GLIDE PATH INDICATOR
USAF INTERIM SYSTEM

SYMBOL KEY

D(MJ - T)	-	DISTANCE (FEET) BETWEEN MARK J AND TOUCHDOWN POINT
D(MJ - MK)	-	DISTANCE (FEET) BETWEEN MARK J AND MARK K
BAND 1	-	RUNWAY SECTION BELOW THE TOUCHDOWN POINT.
BAND J	-	RUNWAY SECTION BETWEEN T + (J-2)X600 AND T + (J-1)X600 FEET (J GREATER THAN 1, LESS THAN 46)
BAND 46	-	RUNWAY SECTION BEYOND T + 5 MILES
N	-	NUMBER OF POINTS CONTRIBUTING TO THE BAND AVERAGE
V-MN	-	MEAN OF THE DEVIATIONS IN THE VERTICAL PLANE
H-MN	-	MEAN OF THE DEVIATIONS IN THE LATERAL PLANE
SD-V	-	STANDARD DEVIATION ABOUT V-MN IN THE VERTICAL PLANE
SD-H	-	STANDARD DEVIATION ABOUT H-MN IN THE LATERAL PLANE
V-MAX	-	MAXIMUM VERTICAL DEVIATION
H-MAX	-	MAXIMUM LATERAL DEVIATION
*	-	STARRED QUANTITY REPRESENTS AN AVERAGE FOR THE ENTIRE SET OF BANDS (EXCEPTING BAND 1)

COMPUTER DATA SHEET C - 1
VISUAL GLIDE PATH INDICATOR
WESTINGHOUSE TRICOLOR SYSTEM

RUN	D(M1 - T)	D(M2 - T)	D(M3 - T)	D(M1 - M2)	D(M2 - M3)	D(M1 - M3)
1	13852.003	6768.562	363.138	7084.635	6407.155	13490.330
2	31647.657	24149.632	2400.985	7562.686	21749.214	29247.372
3	8167.386	4535.665	859.997	3631.973	3676.258	7307.727
4	19503.384	18332.284	4363.698	1171.537	13968.791	15139.822
5	31655.850	8695.932	296.510	22973.417	8400.397	31359.538
6	23007.829	5858.137	1019.906	22150.762	6870.122	29020.656

	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6	BAND 7	BAND 8
N	2	3	5	4	7	4	5	6
V-MN	-2424.780	18.069	-2.127	-1.830	-5.925	-6.846	-17.332	-8.141
SD-V	2499.573	19.464	12.779	8.995	5.664	8.758	28.608	24.500
V-MAX	4924.353	35.673	17.324	14.722	14.850	19.420	67.334	39.923
H-MN	55910.046	7.794	8.186	9.451	5.930	4.623	-0.373	3.617
SD-H	55905.523	6.927	10.626	11.665	11.401	8.284	10.204	5.571
H-MAX	111815.569	17.451	26.113	23.837	20.376	18.209	18.896	10.958

	BAND 9	BAND 10	BAND 11	BAND 12	BAND 13	BAND 14	BAND 15	BAND 16
N	8	5	6	5	4	5	3	3
V-MN	15.447	20.078	60.148	29.133	45.698	125.622	121.760	126.650
SD-V	44.643	63.158	100.279	108.519	137.784	178.312	192.463	207.664
V-MAX	104.691	142.227	215.172	245.850	283.747	360.355	393.939	420.198
H-MN	-2.765	2.412	1.592	10.111	19.801	16.718	22.437	21.235
SD-H	9.265	13.253	14.173	12.744	11.355	15.758	28.692	35.964
H-MAX	15.178	17.916	21.247	29.297	36.492	44.943	55.201	60.440

	BAND 17	BAND 18	BAND 19	BAND 20	BAND 21	BAND 22	BAND 23	BAND 24
N	3	2	2	2	2	5	2	1
V-MN	19.996	-33.522	-52.751	-76.044	-84.349	-104.521	-64.633	68.845
SD-V	65.563	67.259	109.916	151.900	178.162	173.065	151.789	0.
V-MAX	103.804	100.782	162.667	227.944	262.511	259.855	216.422	68.845
H-MN	12.865	30.804	33.750	37.751	40.000	5.921	33.152	75.634
SD-H	36.447	32.617	27.954	23.809	11.175	65.529	26.375	0.
H-MAX	64.133	63.421	61.704	61.561	51.176	123.360	59.527	75.634

COMPUTER DATA SHEET C - 3
VISUAL GLIDE PATH INDICATOR
WESTINGHOUSE TRICOLOR SYSTEM

	BAND 25	BAND 26	BAND 27	BAND 28	BAND 29	BAND 30	BAND 31	BAND 32
N	2	2	2	2	2	2	2	3
V-MN	-135.742	-146.147	-153.654	-156.042	-155.142	-152.518	-149.888	-188.321
SD-V	185.884	180.214	171.934	162.774	157.015	152.962	146.767	130.785
V-MAX	321.625	326.361	325.587	318.816	312.156	305.480	296.655	287.057
H-MN	43.058	50.975	58.110	59.742	65.023	77.591	87.051	92.148
SD-H	52.662	59.433	60.315	59.245	51.860	39.130	19.620	5.805
H-MAX	95.720	110.407	118.426	118.987	116.884	116.722	106.671	100.019

	BAND 33	BAND 34	BAND 35	BAND 36	BAND 37	BAND 38	BAND 39	BAND 40
N	1	1	1	1	1	1	1	1
V-MN	-267.280	-289.648	-314.491	-341.166	-384.261	-416.585	-428.120	-417.564
SD-V	0.	0.	0.	0.	0.	0.	0.	0.
V-MAX	267.280	289.648	314.491	341.166	384.261	416.585	428.120	417.564
H-MN	110.489	112.291	115.276	105.332	74.300	96.451	114.728	141.141
SD-H	0.	0.	0.	0.	0.	0.	0.	0.
H-MAX	110.489	112.291	115.276	105.332	74.300	96.451	114.728	141.141

	BAND 41	BAND 42	BAND 43	BAND 44	BAND 45	BAND 46
N	1	1	0	0	0	0
V-MN	-402.080	-387.152	0.	0.	0.	0.
SD-V	0.	0.	0.	0.	0.	0.
V-MAX	402.080	387.152	0.	0.	0.	0.
H-MN	173.648	200.175	0.	0.	0.	0.
SD-H	0.	0.	0.	0.	0.	0.
H-MAX	173.648	200.175	0.	0.	0.	0.

PERFORMANCE OF THE SYSTEM

*V-MN	-114.448
*SD-V	81.160
*V-MAX	241.960
*H-MN	53.126
*SD-H	18.972
*H-MAX	75.725
*D(M3 - T)	1550.705

6 RUNS HAVE BEEN PROCESSED. THERE IS NO MORE DATA IN THE SET.

COMPUTER DATA SHEET C - 5
VISUAL GLIDE PATH INDICATOR
WESTINGHOUSE TRICOLOR SYSTEM

SYMBOL KEY

D(MJ - T)	- DISTANCE (FEET) BETWEEN MARK J AND TOUCHDOWN POINT
D(MJ - MK)	- DISTANCE (FEET) BETWEEN MARK J AND MARK K
BAND 1	- RUNWAY SECTION BELOW THE TOUCHDOWN POINT
BAND J	- RUNWAY SECTION BETWEEN T + (J-2)X600 AND T + (J-1)X600 FEET (J GREATER THAN 1, LESS THAN 46)
BAND 46	- RUNWAY SECTION BEYOND T + 5 MILES
N	- NUMBER OF POINTS CONTRIBUTING TO THE BAND AVERAGE
V-MN	- MEAN OF THE DEVIATIONS IN THE VERTICAL PLANE
H-MN	- MEAN OF THE DEVIATIONS IN THE LATERAL PLANE
SD-V	- STANDARD DEVIATION ABOUT V-MN IN THE VERTICAL PLANE
SD-H	- STANDARD DEVIATION ABOUT H-MN IN THE LATERAL PLANE
V-MAX	- MAXIMUM VERTICAL DEVIATION
H-MAX	- MAXIMUM LATERAL DEVIATION
*	- STARRED QUANTITY REPRESENTS AN AVERAGE FOR THE ENTIRE SET OF BANDS (EXCEPTING BAND 1)

COMPUTER DATA SHEET D - 1
VISUAL GLIDE PATH INDICATOR
CUMMING-LANE SYSTEM

1	29012.206	24421.496	3348.803	4591.615	21072.706	25663.405
2	32855.452	31822.989	1371.079	2418.250	30473.570	31535.854
3	24909.741	23023.191	6490.583	1903.334	16532.646	18419.543
4	23787.660	22106.608	4757.509	1682.283	17349.118	19030.229
5	22355.998	21798.849	5278.367	557.327	16520.571	17077.720
6	22875.807	22875.807	3755.875	0.	19120.100	19120.100
7	23887.218	21265.502	3220.429	2622.314	18045.354	20667.187
8	25448.675	23301.137	3511.056	2148.583	19790.922	21938.569
9	26747.305	21589.660	6507.975	5159.432	15081.930	20239.716
10	33729.358	22193.638	1690.031	11537.634	20503.623	32039.350
11	24614.559	19123.357	796.031	5495.175	18327.639	23816.700
12	25418.884	19874.477	2053.333	5547.535	17821.300	23365.986
13	22168.985	21588.218	1028.278	686.841	20565.711	21148.485
14	22148.683	19340.708	879.852	4548.738	18479.375	21331.979
15	9883.625	8109.612	994.530	3424.649	7137.599	9038.681
16	29795.704	29046.750	1193.368	2354.406	27854.637	28611.388
17	19151.533	16221.202	1755.749	2930.890	14465.556	17395.839
18	34931.458	32974.541	1481.774	1957.089	31492.772	33449.689
19	27767.591	23498.704	2310.402	4354.012	21183.641	25460.158
20	14033.068	12619.549	2899.083	2007.067	9828.661	11350.997
21	29581.071	5919.237	1254.954	23666.385	4664.922	28328.111
22	27054.249	21363.077	1896.795	5691.690	19466.316	25157.477
23	27268.576	17796.446	2557.244	9512.777	15241.182	24715.661
24	24908.639	17897.699	1458.674	7035.522	16434.757	23449.653

COMPUTER DATA SHEET D - 2
VISUAL GLIDE PATH INDICATOR
CUMMING-LANE SYSTEM

RUN	D(M1 - T)	D(M2 - T)	D(M3 - T)	D(M1 - M2)	D(M2 - M3)	D(M1 - M3)
25	27318.134	21259.167	2164.986	6297.355	19094.255	25157.906
26	27093.764	22555.197	1966.757	5000.087	20588.804	25138.201
27	26690.860	19948.215	1069.088	6745.836	18879.584	25622.505
28	29259.911	21428.853	2368.008	8057.326	19060.916	26899.953
29	23869.259	18375.027	2279.545	5603.814	16095.597	21594.127

	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6	BAND 7	BAND 8
N	0	1	11	15	18	17	23	24
V-MN	0.	14.012	8.632	7.913	7.017	11.445	40.049	13.902
SD-V	0.	0.	15.062	16.582	10.386	27.654	122.840	27.400
V-MAX	0.	14.012	45.366	35.625	25.058	111.148	601.146	112.656
H-MN	0.	-24.042	-1.471	5.301	4.022	4.139	-1.108	2.163
SD-H	0.	0.	30.662	24.190	17.709	21.262	29.208	22.247
H-MAX	0.	24.042	74.813	83.478	33.516	55.837	110.778	40.370

	BAND 9	BAND 10	BAND 11	BAND 12	BAND 13	BAND 14	BAND 15	BAND 16
N	25	25	27	29	27	28	28	28
V-MN	17.994	421.058	19.169	25.558	17.212	35.373	18.662	35.235
SD-V	29.029	1962.279	36.005	45.197	44.638	54.047	64.213	63.026
V-MAX	119.221	10033.033	115.108	114.938	102.354	153.650	232.103	274.938
H-MN	-7.927	1196.636	-20.935	-51.886	14.944	-160.824	-2.544	-20.468
SD-H	52.645	5945.130	116.593	170.496	148.906	506.572	45.071	124.206
H-MAX	214.066	30319.206	587.150	862.873	724.009	2202.365	93.189	613.727

	BAND 17	BAND 18	BAND 19	BAND 20	BAND 21	BAND 22	BAND 23	BAND 24
N	24	29	29	25	27	27	26	25
V-MN	79.870	26.108	25.385	40.788	36.936	27.432	19.020	41.105
SD-V	218.419	45.122	69.549	81.221	86.170	101.994	65.035	106.654
V-MAX	1075.980	120.846	320.527	333.635	352.956	383.912	131.170	400.224
H-MN	-43.115	-55.153	-71.241	-93.149	-114.043	-154.341	-30.355	-59.837
SD-H	186.687	231.695	294.434	396.229	472.282	572.593	133.081	169.890
H-MAX	892.948	1219.936	1590.901	2000.018	2478.856	3017.747	504.246	710.870

COMPUTER DATA SHEET D - 4
VISUAL GLIDE PATH INDICATOR
CUMMING-LANE SYSTEM

	BAND 25	BAND 26	BAND 27	BAND 28	BAND 29	BAND 30	BAND 31	BAND 32
N	24	23	26	24	24	22	26	22
V-MN	49.942	40.099	31.316	39.202	43.921	23.047	44.047	43.961
SD-V	120.111	121.296	113.473	119.117	121.317	117.255	132.242	125.695
V-MAX	398.176	384.831	390.721	386.871	362.756	317.485	280.872	245.643
H-MN	-70.364	-73.069	-98.057	-123.610	-158.362	-210.276	-200.811	-233.165
SD-H	212.428	259.983	295.636	377.926	462.759	567.327	644.482	714.750
H-MAX	942.269	1200.950	1484.808	1800.550	2147.306	2522.882	2929.222	3370.215

	BAND 33	BAND 34	BAND 35	BAND 36	BAND 37	BAND 38	BAND 39	BAND 40
N	25	19	20	19	21	12	9	7
V-MN	13.716	33.029	3785.067	46.623	27.558	-8.742	35.978	0.416
SD-V	118.948	101.819	15075.524	109.576	108.493	85.083	91.826	91.236
V-MAX	262.629	241.033	69263.724	266.351	261.795	144.462	167.369	167.727
H-MN	-219.307	-122.128	5034.875	-160.870	-168.304	-79.705	-29.467	-36.410
SD-H	775.887	306.436	22453.138	433.081	487.265	129.814	138.991	149.913
H-MAX	3853.977	1271.706	102893.506	1885.969	2264.717	290.099	264.795	236.122

	BAND 41	BAND 42	BAND 43	BAND 44	BAND 45	BAND 46
N	7	4	3	3	3	28
V-MN	22.773	-40.546	-116.240	-125.124	-138.902	-213.007
SD-V	114.699	117.950	72.191	67.498	62.937	80.408
V-MAX	173.979	199.242	213.182	220.536	226.806	314.169
H-MN	12.740	10.211	-29.185	-37.861	-61.995	-764.842
SD-H	138.999	143.495	163.835	181.108	197.639	956.375
H-MAX	216.645	229.706	255.465	290.927	340.404	3562.088

PERFORMANCE OF THE SYSTEM

*V-MN	· 7.390	
*SD-V	115.692	(Omitted bands 7, 10, 17, and 35)
*V-MAX	222.709	
*H-MN	55.440	
*SD-H	886.734	
*H-MAX	4060.206	
*D(M3 - T)	2494.833	

29 RUNS HAVE BEEN PROCESSED. THERE IS NO MORE DATA IN THE SET.

COMPUTER DATA SHEET D - 6
VISUAL GLIDE PATH INDICATOR
CUMMING-LANE SYSTEM

SYMBOL KEY

D(MJ - T)	- DISTANCE (FEET) BETWEEN MARK J AND TOUCHDOWN POINT
D(MJ - MK)	- DISTANCE (FEET) BETWEEN MARK J AND MARK K
BAND 1	- RUNWAY SECTION BELOW THE TOUCHDOWN POINT
BAND J	- RUNWAY SECTION BETWEEN T + (J-2)X600 AND T + (J-1)X600 FEET (J GREATER THAN 1, LESS THAN 46)
BAND 46	- RUNWAY SECTION BEYOND T + 5 MILES
N	- NUMBER OF POINTS CONTRIBUTING TO THE BAND AVERAGE
V-MN	- MEAN OF THE DEVIATIONS IN THE VERTICAL PLANE
H-MN	- MEAN OF THE DEVIATIONS IN THE LATERAL PLANE
SD-V	- STANDARD DEVIATION ABOUT V-MN IN THE VERTICAL PLANE
SD-H	- STANDARD DEVIATION ABOUT H-MN IN THE LATERAL PLANE
V-MAX	- MAXIMUM VERTICAL DEVIATION
H-MAX	- MAXIMUM LATERAL DEVIATION
*	- STARRED QUANTITY REPRESENTS AN AVERAGE FOR THE ENTIRE SET OF BANDS (EXCEPTING BAND 1)

COMPUTER DATA SHEET E - 1
VISUAL GLIDE PATH INDICATOR

RUN	D(M1 - T)	D(M2 - T)	D(M3 - T)	D(M1 - M2)	D(M2 - M3)	D(M1 - M3)
1	23606.445	20705.192	745.391	2901.770	19959.965	22861.259
2	26777.770	17158.707	1546.693	9619.247	15612.128	25231.237
3	34513.899	25753.406	325.727	8773.836	25427.708	34188.257
4	26091.555	20611.448	1471.680	5480.589	19139.958	24620.144
5	10644.104	9231.678	57.052	1927.316	9283.438	10694.202
6	27347.782	16947.074	487.212	10408.297	16460.003	26860.675
7	20204.145	20204.145	483.903	0.	19722.021	19722.021
8	22645.799	16689.045	1861.779	5957.527	14940.861	20890.893
9	22413.362	17571.144	92.682	4845.149	17648.152	22490.401
10	22714.372	17909.335	601.564	4805.650	17307.957	22112.999
11	2993.289	2993.289	328.812	0.	2664.537	2664.537
12	28158.588	27445.140	814.654	714.219	26630.628	27344.090
13	31358.443	31358.443	31358.443	0.	0.	0.
14	23991.454	13622.464	661.560	10372.390	12961.039	23329.923
15	24360.057	22758.815	655.969	1602.084	22102.855	23704.099
16	27151.734	26418.667	330.015	976.843	26090.899	26824.895
17	23519.234	18579.290	1376.480	4965.076	17203.042	22143.039
18	29650.301	13115.957	146.358	16539.299	12980.924	29515.542
19	26332.067	26332.067	1281.660	0.	25050.569	25050.569
20	9857.434	9857.434	556.865	0.	9308.243	9308.243
21	27063.344	20071.675	1005.733	7012.295	19066.581	26057.787
22	24389.240	20255.597	878.134	4271.015	19381.611	23516.002
23	16457.390	16457.390	293.027	0.	16747.513	16747.513

COMPUTER DATA SHEET E - 2
VISUAL GLIDE PATH INDICATOR
ROYAL AIRCRAFT ESTABLISHMENT SYSTEM

	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6	BAND 7	BAND 8
N	8	16	19	23	26	22	27	24
V-MN	67.178	-597.854	8.251	-2.943	7.737	5.663	1.247	8.581
SD-V	2517.214	1635.420	23.625	17.113	40.047	19.783	23.372	23.539
V-MAX	5143.477	4924.353	85.145	42.930	183.429	62.241	59.251	49.875
H-MN	13972.557	13977.801	3.541	-25.297	51.646	-1.612	20.186	2.121
SD-H	36981.186	36979.203	16.738	123.767	240.061	28.576	91.505	42.368
H-MAX	111815.569	111815.569	45.285	602.360	1247.589	83.382	464.367	137.357

	BAND 9	BAND 10	BAND 11	BAND 12	BAND 13	BAND 14	BAND 15	BAND 16
N	21	25	23	23	22	22	23	22
V-MN	9.596	10.201	19.167	16.489	26.121	29.779	30.883	50.308
SD-V	23.837	30.050	31.348	36.520	35.600	30.020	31.245	40.719
V-MAX	44.967	56.689	57.368	119.934	106.352	84.261	91.674	126.949
H-MN	-9.443	-18.154	-26.802	5.026	-50.029	-66.996	-43.091	-175.533
SD-H	54.910	70.881	110.474	36.196	155.516	216.320	189.435	433.354
H-MAX	204.394	285.906	393.506	95.261	531.618	778.377	911.541	1482.783

	BAND 17	BAND 18	BAND 19	BAND 20	BAND 21	BAND 22	BAND 23	BAND 24
N	24	23	20	23	19	22	22	20
V-MN	35.952	48.494	52.533	49.041	36.279	49.861	38.230	38.685
SD-V	49.707	60.058	52.498	54.825	65.553	65.521	76.340	90.364
V-MAX	127.612	174.919	183.821	170.434	176.845	180.166	248.365	304.615
H-MN	-102.901	-94.278	-6.319	0.226	12.256	29.505	14.933	23.475
SD-H	524.918	383.429	58.697	59.323	74.383	83.053	84.426	87.884
H-MAX	1938.188	1880.755	138.015	172.688	199.160	233.007	220.434	183.873

	BAND 25	BAND 26	BAND 27	BAND 28	BAND 29	BAND 30	BAND 31	BAND 32
N	20	17	18	20	17	18	14	10
V-MN	39.856	41.575	28.167	40.511	42.618	40.448	47.021	42.985
SD-V	91.733	98.933	84.359	90.539	90.213	79.112	80.159	69.298
V-MAX	301.955	266.087	231.435	241.376	269.340	180.883	210.596	148.501
H-MN	45.004	43.523	20.660	23.074	12.199	13.012	10.310	37.739
SD-H	96.094	97.339	87.678	81.022	93.229	82.935	102.893	97.824
H-MAX	214.704	219.049	196.155	196.194	189.796	179.292	170.111	170.124

	BAND 33	BAND 34	BAND 35	BAND 36	BAND 37	BAND 38	BAND 39	BAND 40
N	12	12	11	7	8	6	5	5
V-MN	-12.961	-2.900	-8.721	-4.847	-31.221	30.662	-29.086	-8.132
SD-V	78.098	71.519	66.196	66.031	62.371	53.883	78.700	88.775
V-MAX	186.122	141.925	100.272	94.256	124.057	84.376	148.699	153.227
H-MN	-24.434	-8.001	-2.965	35.631	-20.125	41.946	75.377	126.976
SD-H	120.524	125.251	137.920	149.743	192.354	144.640	172.516	140.533
H-MAX	199.458	232.283	255.187	254.613	306.819	229.167	266.197	290.503

	BAND 41	BAND 42	BAND 43	BAND 44	BAND 45	BAND 46
N	5	6	4	6	6	14
V-MN	-19.468	-53.302	10.326	-42.349	-56.399	-89.397
SD-V	99.241	115.074	82.271	106.275	160.658	125.624
V-MAX	182.433	198.276	131.175	161.265	332.956	293.375
H-MN	138.394	163.256	88.625	57.150	-368.852	-173.760
SD-H	150.141	155.610	163.402	177.148	960.548	660.187
H-MAX	312.826	320.356	283.092	323.825	2445.848	1924.717

COMPUTER DATA SHEET E - 4
VISUAL GLIDE PATH INDICATOR
ROYAL AIRCRAFT ESTABLISHMENT SYSTEM

PERFORMANCE OF THE SYSTEM

*V-MN	13.080	
*SD-V	65.015	(Omitted band 2)
*V-MAX	157.282	
*H-MN	307.889	
*SD-H	985.221	
*H-MAX	2960.572	
*D(M3 - T)	726.952	(Omitted Run 13)

23 RUNS HAVE BEEN PROCESSED. THERE IS NO MORE DATA IN THE SET.

COMPUTER DATA SHEET E - 5
VISUAL GLIDE PATH INDICATOR
ROYAL AIRCRAFT ESTABLISHMENT SYSTEM